MAJOR PROGRAM ELEMENTS FOR AN ADVANCED GEOSCIENCE OIL AND GAS RECOVERY RESEARCH INITIATIVE

Volume II

Technical Subcommittees Program Summary

Prepared
on Behalf of

U.S. Department of Energy
Office of Fossil Energy

Conducted by

The Geoscience Institute for
Oil and Gas Recovery Research
The University of Texas at Austin
University Station, Box X
Austin, TX 78713-7508

A National Consortium

University of Alabama
State of Alaska
Colorado School of Mines
University of Houston
Illinois State Geological Survey
University of Kansas
Louisiana State University
Mississippi State University
New Mexico Institute of Mining and Technology
State of North Dakota
University of Oklahoma
Pennsylvania State University
Stanford University
Texas A&M University
University of Texas at Austin
University of Tulsa
West Virginia Geological and Economic Survey
University of Wyoming

September 1988

GEOSCIENCE INSTITUTE FOR OIL AND GAS RECOVERY RESEARCH

M. E. Milling, Executive Director

TECHNICAL SUBCOMMITTEES

Field Reservoir Frameworks

D. J. Benson, Univ. Alabama*
W. Jamison, Amoco Production*
T. Cross, Colorado Sch. Mines
N. F. Hurley, Marathon Oil
J. M. Johnston, Energy Omega
R. Kornbrath, Alaska Oil & Gas
K. Larner, Colorado Sch. Mines
R. Loucks, ARCO Oil & Gas
R. C. Shumaker, West Virginia Univ.
C. B. Wason, Geophysical Service Inc.
W. L. Watney, Kansas Geol. Survey

Reservoir Characterization

N. Tyler, Bur. Econ. Geol., Un. Texas*
T. Hewett, Chevron Oil Field Res.*
B. Iverson, Univ. Wyoming
H. Jahns, Exxon Prod. Res.
A. Journel, Stanford Univ.
S. C. Leininger, Mobil E&P Services
R. L. Mathis, Shell Western E&P
J. A. McDonald, Univ. Houston
D. F. Oltz, Illinois St. Geol. Survey
R. J. Robinson, Texaco Houston Res.

Reservoir Performance Prediction

L. W. Lake, Univ. Texas at Austin*
H. Kazemi, Marathon Oil*
M. A. Adewumi, Penn State Univ.
A. Carnes, Core Labs
A. Dandona, Mobil E&P
R. E. Ewing, Univ. Wyoming
M. J. King, BP America Inc.
D. A. Lawson, Stanford Univ.
F. M. Orr, Jr., Stanford Univ.

Advance Extraction Technology

D. W. Green, Univ. Kansas*
R. N. Healy, Exxon Prod. Research*
J. L. Cayias, Sun E&P Co.
L. L. Handy, Univ. So. California
J. Hanor, Louisiana State Univ.
M. M. Prats, Shell Development
F. I. Stalkup, ARCO Exploration Tech.
W. C. Tosch, Penn State University
E. Witterholt, Standard Oil Production

Stimulation and Completion

R. A. Startzman, Texas A&M Univ.*
R. W. Veatch, Amoco Prod. Research*
J. Brill, Univ. Tulsa
G. R. Coulter, Sun E&P Co.
A. Daneshy, Haliburton Services
J. T. Engelder, Penn State Univ.
A. D. Hill, Univ. Texas at Austin

Resource Assessment, Data Bases, and Technology Transfer

J. M. Forgotson, Jr., Univ. Oklahoma*
W. F. Diggons, Schlumberger*
S. Ameri, West Virginia Univ.
K. Aminiam, West Virginia Univ.
S. Bhagwat, Illinois St. Geol. Survey
J. S. Fischer, Landmark Graphics
J. Grace, ARCO E&P
C. G. Groat, Louisiana Geol. Survey
R. A. Mason, Mason Production
E. H. Mayer, Thums
E. D. McKay, Illinois St. Geol. Survey
D. E. Powley, Amoco Prod. Res.
P. Rose, Kansas State University
P. H. Stark, Petroleum Information

*co-chairmen

TECHNICAL SUBCOMMITTEES PROGRAM SUMMARY REPORT

INTRODUCTION

The Geoscience Institute for Oil and Gas Recovery Research, established by The University of Texas at Austin in February 1988, is composed of a national consortium of universities and other nonprofit state entities with advanced oil and gas recovery research programs in petroleum engineering, geophysics, and geology. The participating organizations are regionally representative of all major hydrocarbon-producing provinces of the U.S.

The Institute was established to

- help provide a more focused approach for the public sector's oil and gas recovery research programs;
- develop a unified basis and constituency for increased broad-based support of university and state agency research; and
- facilitate a mechanism for identifying and coordinating multiuniversity programs with joint industry and Department of Energy support.

The Geoscience Institute was awarded a contract in April 1988 by DOE's Office of Fossil Energy to make a study of the major program elements, research activities, and costs required to establish a comprehensive geoscience oil and gas recovery research initiative. The general plan and scope of the study were developed based on discussions and reviews with personnel from the Office of Fossil Energy, industry representatives, and the Institute's Board of Directors. From the beginning, there was a strong commitment to incorporate a broad, multidisciplinary, technical base into the study. Therefore, during the course of the study, representatives from academia, state and federal agencies, and industry with a range of technical disciplines were invited and encouraged to participate in various phases of the study program.

The focus of this current study is on recovery research needs and opportunities and not exploration. The major goal of this study is to identify program priorities required for development of new concepts, advanced reservoir models, and technology to maximize recovery of mobile and immobile oil and natural gas resources from existing fields. Following the Energy Research Advisory Board's (ERAB) Solid Earth Sciences Panel recommendation, a major focus of the study is on shorter term, lower risk research opportunities for improving recovery efficiency from existing fields.

The recommended highest priority research activities are aimed at delineating and improving efficiencies in the recovery of unswept and uncontacted mobile oil, immobile oil, and untapped gas in existing reservoirs. A principal research goal is the development of technological tools and techniques to provide better understanding of the internal geological complexities in reservoirs in order that wells can be drilled strategically based on a geoscientifically targeted basis, rather than the customary uniform spacing. Such targeting will improve our ability to place wells at optimum locations to contact reservoir compartments to capture mobile oil reserves and provide for more effective enhanced oil recovery process applications from existing reservoirs at lower cost.

The results from this study are summarized in three volumes. Volume I is the Summary Program Study Report and contains the key program recommendations, description of the highest priority research activities, and a strategy for program implementation. The Technical Subcommittees Program Summary Reports (this volume), covering six major program elements and a comprehensive description of all related research activities, is contained in Volume II. Summary reports from a series of Regional Technical Forums that focused on technology needs related to specific hydrocarbon provinces are presented in Volume III.

Technical Program Elements

The Institute's Technical Study Committee established six Technical Subcommittees to address the research needs of the major technical program elements identified by the Board of Directors. The subcommittees were composed of recognized experts in their disciplines and were responsible for identification and prioritization of research activities related to the major program elements.

The major technical program elements that formed the basis for the program study were defined by the Technical Study Committee and approved by the Board. The major technical program elements are briefly described and outlined below:

- Field Reservoir Frameworks

  The occurrence and distribution of reservoirs and their intrafield variability are controlled by the stratigraphic and structural framework. Targeting development wells to extend field limits, test undrained fault segments, and evaluate deeper pool potential requires establishment of the geological framework for the field. Field framework studies also provide a basis for detailed reservoir characterization.

- Reservoir Characterization

Improved reservoir models delineating patterns of geologic heterogeneities are required to determine the distribution of reservoir flow units and target remaining mobile oil, immobile oil, and undrained natural gas resources in existing fields for strategically directed infill drilling programs. Reservoir characterization studies provide the basic input required for development of simulation models.

- Reservoir Performance Prediction

The goal of reservoir simulation is to utilize geologic and engineering data mathematically to represent reservoir performance. Because of the complexity of both reservoir geology and the physics and chemistry of recovery processes, improvements are needed to better represent geologic heterogeneity, to appropriately average and scale-up point measurements of petrophysical properties, and to develop improved numerical techniques for increased computational accuracy and speed.

- Advanced Extraction Technology

Improved understanding of capillarity, mobility, and miscibility and their relationship to reservoir recovery processes is required to develop advanced extraction technologies.

- Stimulation and Completion Technology

  Unswept oil and gas in low-permeability zones provide significant targets for additional recovery. Accurately contacting these pay zones will require improved formation evaluation, well completion techniques, and stimulation methods.

- Resource Assessment, Data Bases, and Technology Transfer

  Characteristics and hydrocarbon reserves and resources for existing fields will be documented. Such a data base will provide a basis for prioritizing and selecting areas for technology deployment and research emphasis.

  Success of the advanced geoscience research initiative will depend on how well new understandings, concepts, and technological developments can be transferred to the operators and service companies. Efficient technology transfer requires establishing effective publications, special seminars and workshops, continuing education courses, and joint cooperative programs with industry.

Identification of Research Activities

The Technical Subcommittees drew heavily from the Regional Technical Forum reports and their own personal background experience in developing their research program summary reports. The Technical Study Committee provided guidance as appropriate.

The Institute's Technical Coordinators developed a format for preparation of subcommittee reports (Fig. 1). First, each major technical program element was subdivided into individual key research areas. Second, research activities related to the areas were identified. Finally, on a selected basis, example projects were included for each research area. The research activities represent the basic building blocks of the research study plan and essentially correspond to a program level status. As outlined in Figure 1, the subcommittees subdivided the technical program elements into 41 research areas and 167 associated research activities with 289 example projects.

The Institute's Technical Coordinators provided liaison for the subcommittees, but to a large degree the subcommittees worked independently and, as would be expected, in some cases identified similar research activities and projects. There has been no attempt to remove duplication or redundancy in the final subcommittee reports. The Technical Study Committee with the Institute's Technical Coordinators had the responsibility to synthesize the subcommittee reports and develop a coherent study program recommendation.

Prioritization of Research Activities

As previously mentioned, the Technical Subcommittees identified a total of 167 research activities requiring an estimated research program funding level of approximately $125 million. In order to develop optional program opportunities at reduced funding levels the Technical Subcommittees prioritized identified research activities into first-, second-, and third-priority categories. Priority ranking of the research activities by the subcommittees was based on the following criteria:

MAJOR PROGRAM ELEMENTS, RESEARCH AREAS, ACTIVITIES AND EXAMPLE PROJECTS FOR AN ADVANCED GEOSCIENCE OIL AND GAS RECOVERY RESEARCH INITIATIVE

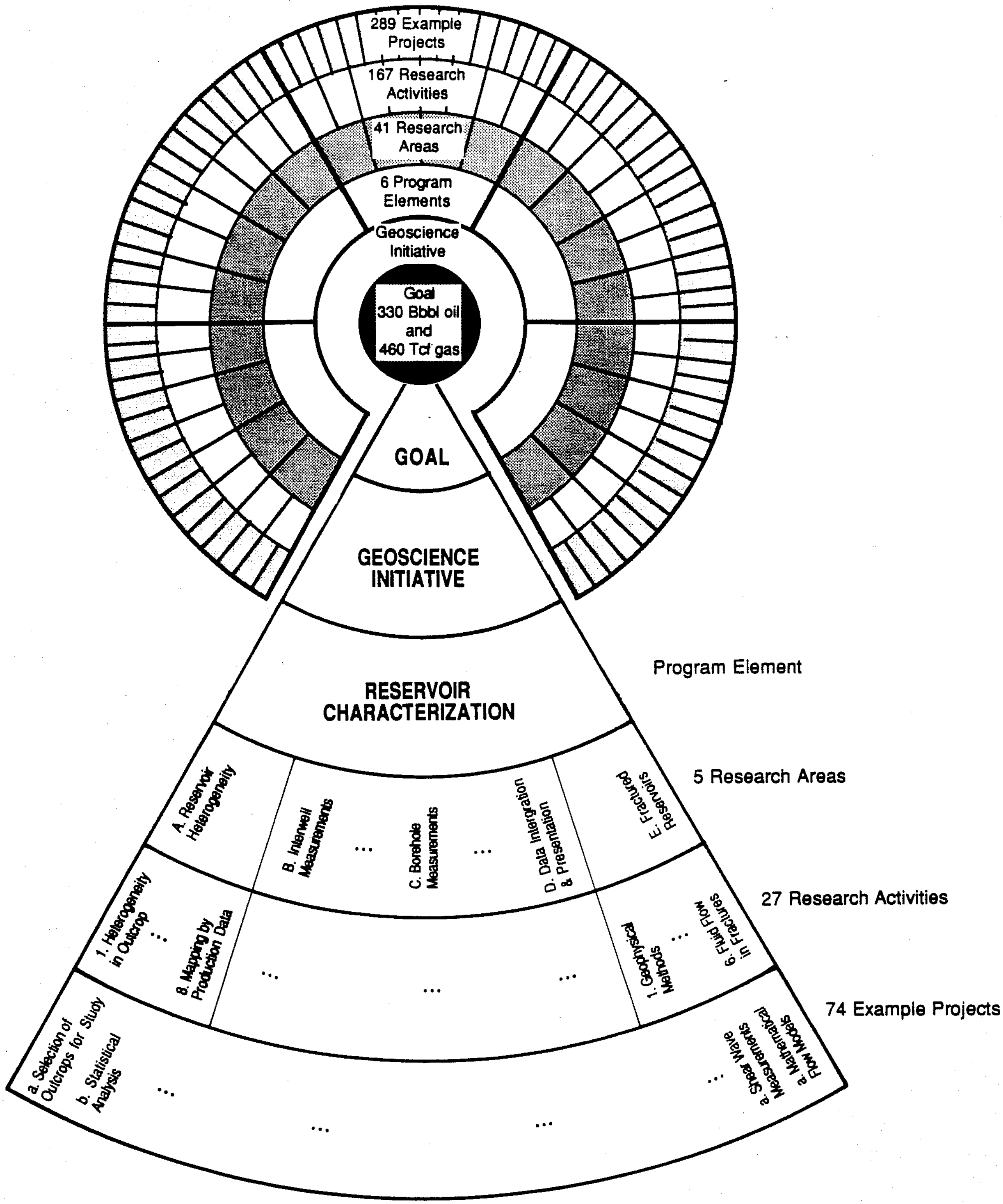

FIGURE 1

- Potential Payout: First priority research activities must have a relatively high potential benefit or payout. If successful, they would significantly advance the science and technology associated with their application.

- Multidisciplinary Approach: Activities that have potential application across disciplines and provided for interfaces between disciplines were generally ranked higher than more narrowly focused research opportunities.

- Probability of Success: Research activities identified with new approaches that were judged most likely to provide successful results were generally ranked higher. Certain high potential payout activities with low chance of success were generally ranked lower.

- University Program Capability: There was an attempt to rank activities based on their appropriateness to be undertaken by university and/or state agency researchers. Certain research activities are best suited to be carried out within industry. Therefore, high-cost activities requiring large research staffs and access to unique analytical/test equipment were ranked lower.

- Match Funding Opportunities: It was recognized that the major operating companies would be more inclined to support research activities that complemented their ongoing established programs. Therefore, the subcommittees generally attempted to identify higher priority research activities that did not directly duplicate industry's research efforts.

Based on the ranking criteria, the subcommittees independently identified 66 top or Priority 1 research activities. Likewise, in the same manner, 61 Priority 2 and 40 Priority 3 research activities were identified as so indicated in the subcommittee reports.

In light of anticipated limits on potential early program funding for oil and gas recovery research, the activities were further prioritized to better focus on current highest priority needs. The subcommittees cochairmen together with the Technical Study Committee reprioritized all 66 Priority 1 research activities into top, middle, and lower percentile categories which were respectively designated A, B, and C priority. On this basis, 26 Priority 1, A-ranked activities were identified. Likewise, 18 Priority 1, B-ranked, and 22 Priority 1, C-ranked activities were identified (Table 1-1).

Based on the priority ranking of research activities, the Technical Study Committee and subcommittees cochairmen developed program options at $10 MM, $20 MM, and $50 MM levels which are summarized in Volume I.

SUMMARY OF PRIORITIZED FIRST-ORDER RESEARCH ACTIVITIES

BY MAJOR PROGRAM ELEMENT

	Priority*
FIELD RESERVOIR FRAMEWORKS	
Development and Application of Empirically Derived Four-Dimensional Stratigraphic Models	
• Develop 4-D genetic stratigraphic and sequence stratigraphic characterization of facies models	A
• Provide empirical quantitative data for facies models	C
Identification of Intrafield Diagenetic Variability and Porosity Basement	
• Improve modeling of intrafield diagenetic variability	C
Mesoscale to Macroscale Deformational Features	
• Determine nature, orientation, and intensity of deformational features for different reservoir rock types	A
• Convert geological descriptions into quantitative flow parameters usable in reservoir modeling	B
• Determine reservoir partitioning effectiveness of intrafield faults as a function of fault type, displacement, and affected lithologies	B

TABLE 1-1

* see text

Numerical Geological Modeling and Geoscientific Workstations	
• Develop improved forward process-response geological models	A
• Improve methodology for inverse geological models	C
Delineation and Understanding of Pressure Cells	
• Determine the geometry and structure of pressure cell boundaries	B
High-Resolution Seismic Imaging for Field Definition	
• Develop enhanced seismic vertical resolving power	A
• Extend methodology for structural and stratigraphic interpretation of seismic data	C
• Improve borehole seismic methods	C
• Provide derivation of lithologic, stress-fracture, and fluid information from multicomponent seismic data	A

RESERVOIR CHARACTERIZATION

Recognition and Quantification of Reservoir Heterogeneity	
• Investigate heterogeneity in outcrop of reservoir equivalents	A
• Improve rapid subsurface methods to identify heterogeneity types	A
• Determine impact of geologic heterogeneity on reservoir performance and hydrocarbon remaining saturations	A
• Improve methods for use of production data to predict remaining unrecovered hydrocarbons	B

Research on Interwell Measurements

- Test and evaluate well/well seismic method — B
- Improve 3-D seismology for lithology and fluid predictions — A

Research on Borehole Measurements

- Determine rock and fluid properties derived from logs — B

Integration of Numerical and Interpretive Information

- Develop methods for quantifying, processing, and combining reservoir information from different sources — A

Fractured Reservoirs

- Develop geophysical methods for characterizing fractures — C
- Determine the statistical characteristics of fracture networks — C

RESERVOIR PERFORMANCE PREDICTION

Nonsimulation Methods

- Improve statistical correlation methods — A

Accurate Numerical Simulator Input

- Use deterministic modeling methods — C
- Improve stochastic-geostatistical methods — C

Fluid Flow Physics

- Basic fluid flow studies — A
- Near-well and wellbore effects — B

Numerical Issues

- Local grid refinement — B
- Stability of hysteresis representations — C

Scale-Up: Lab-Pattern Element (Pilot)-Section-Field.
Requires Local Physics, Geologic Description, Process

- Improve averaging procedures — A
- Improve numerical methods to account for scaling — B

Flow Representation in Nonuniform, Heterogeneous Fields

- Modeling of fractures, faults, and solution channels — C
- Flow barriers, shales, etc. — C

Numerical Simulator Validation

- Use physical models (CT scanning) — A
- Improve convergence analysis methods — C

ADVANCED EXTRACTION TECHNOLOGY

Rock/Fluid Properties and Interactions

- Rock/fluid interactions — A
- Fluid properties — C
- Rock properties — B

Increased Volumetric Sweep Efficiency

- Mobility control — A
- Near-well profile control and in-depth permeability modification — A

Predicting Field Performance from Laboratory Studies

- Laboratory studies of dispersive mixing and viscous fingering — C

Improved Understanding of Process Mechanisms

- Miscible/immiscible gas — B
- Foam/emulsion — B

Process Enhancement

- Simulation of EOR processes in horizontal wells — C

STIMULATION AND COMPLETION TECHNOLOGY

Horizontal Wellbores

- Completions (radius, orientation, location in pay, type) — B
- Production modeling and simulation — A

Perforating

- Downhole performance evaluation techniques — B
- Stress effect on charge performance — C

Reservoir and Wellbore Interaction	
• Modeling multiphase flow and inflow performance behavior in completion intervals	A
• Transient phenomena	C
Formation Evaluation	
• Methods to measure hydrocarbon/water saturations behind pipe	A
Monitoring and Control Systems	
• Downhole to surface data transmissions	C
Hydraulic Fracturing	
• Rock mechanics and in-situ stress characterization	A
• Fracture conductivity	B
• Fracturing processes	A
• Fracturing fluid behavior	B
• Simulation and modeling	A
Acidizing and Other Chemical Stimulation	
• Numerical modeling of matrix acidizing	C
Cementing	
• Displacement mechanisms studies	C
• Bond logging interpretation methods	A

RESOURCE ASSESSMENT, DATA BASES, AND TECHNOLOGY TRANSFER

Resource Assessment

- Develop methodology for an assessment of unrecovered oil and gas fields on a national basis — A

Existing Data Bases

- Inventory and index digital hard copy data resources data sets — B

Development of New Data Bases

- Establish data standards and policies for uniform data base structures — C

Technology Transfer

- Catalog, correlate, and integrate existing improved oil recovery data — B
- Communicate and inform operators, professionals, researchers, and service companies of new approaches — A

FIELD RESERVOIR FRAMEWORKS

Geoscience Institute
Technical Subcommittee Report

for

U.S. Department of Energy
Office of Fossil Energy

Prepared by

Donald J. Benson, University of Alabama*
William Jamison, Amoco Production Company*
Tim Cross, Colorado School of Mines
Neil F. Hurley, Marathon Oil Company
John M. Johnson, Energy Omega Inc.
Richard Kornbrath, Alaska Division of Oil and Gas
Ken Larner, Colorado School of Mines
Bob Loucks, ARCO Oil & Gas Company
Robert C. Shumaker, University of West Virginia
Cameron B. Wason, Geophysical Service Inc.
W. Lynn Watney, Kansas Geological Survey

*Subcommittee Co-chairmen

FIELD RESERVOIR FRAMEWORKS

PROBLEM DEFINITION

Delineation of the stratigraphic, structural, and diagenetic features controlling the distribution and interconnectedness of reservoirs in a field area is critical for efficiently and effectively developing and extending field limits and pay zones, testing undrained reservoir compartments, and evaluating production potential of untested zones. Intrafield variability in petrophysical properties of reservoirs, at macroscopic scales, is a product of the geologic history of the reservoir strata, including depositional and structural history, and historical fluid flow through and diagenetic modifications of the strata. More detailed and accurate characterization of reservoirs may be achieved through development of an accurate geological field framework.

The major objectives of field reservoir framework characterization are to:

- Define field limits and reservoir compartments within a stratigraphic and structural context.
- Determine the nature of reservoir compartments, their boundaries, and their interconnectedness in terms of parameters that can eventually be used to define the overall fluid flow properties of the system.
- Define techniques useful in identification of deeper, untapped reservoirs.

BACKGROUND AND STATUS

Present day methodologies in geological and geophysical delineation of reservoir frameworks provide only the most basic data necessary in the efficient recovery of hydrocarbons. These methodologies were developed largely as an aid to explorationists and are an order of magnitude away from providing the precision necessary to accurately define reservoir limits and the large-scale heterogeneities needed for enhanced oil recovery.

Geological studies have concentrated on the development of facies models for various depositional systems. While models are available for most systems, the quantitative data for these models need to be more accurate to predict reservoir geometries and to identify fluid flow properties of the various components of the system that are critical for efficient hydrocarbon recovery.

Accurate geophysical delineation of reservoir boundaries and internal heterogeneities requires higher resolution data than are currently available. Until recently, the seismic method (including 3-D seismic) has been primarily geared toward exploration and has only begun to approach the resolving power necessary to accurately identify reservoir limits and target infill drilling. New seismic sources, receivers, and acquisition geometries and improved recording, processing, and interpretation techniques are needed to provide the required resolution from this critically important and potentially most powerful of tools for characterization of field reservoir frameworks.

RESEARCH APPROACH

Research pertaining to Field Reservoir Frameworks should develop concepts and tools for detection, description, extrapolation, and prediction of distinct reservoirs within a field, boundaries separating these reservoir units, and overall limits of the field. Currently, reservoir descriptions provided by geoscientists commonly are qualitative and/or generalized, and are couched in geological terms not readily convertible into terms useful for the description of macroscopic fluid flow within a field. It is imperative that research in Field Reservoir Frameworks focuses on refining the parameters that can be used to define the plumbing system of individual reservoirs and the entire field in quantitative terms. Delineation of individual reservoirs and reservoir partitioning faults will rely on improved surface and borehole geophysical tools, acquisition and processing. Stratigraphic, diagenetic, and deformational models, geological and geostatistical, provide the foundation for extrapolating from available borehole information. Recognition and investigation of pressure cells, which are not genetically well understood, can be critical to the development of defined reservoirs in a field and to the inference of additional reservoir units. Development of integrated geological/geophysical/production workstations would provide the ultimate vehicle for efficiently applying the various forms of information pertaining to Field Reservoir Frameworks.

RESEARCH AREAS

Area A. Development and Application of Empirically Derived Four-Dimensional Stratigraphic Models

Facies-controlled compartmentalization of hydrocarbons at the field level can be defined through the development and application of empirically derived regional- and field-scale, four-dimensional, process-response stratigraphic facies models. These models should emphasize flow units for various depositional systems in different tectonic settings with the goal of expressing stratal geometries and their spatial relationship through time. These models need to be based on integrated studies of contemporary environments and their ancient analogs.

Activities

Activity 1. 4-D genetic stratigraphic and sequence stratigraphic characterization of facies models

Characterize and catalog facies models within the context of sequence stratigraphy and tectonic history to define most likely facies types associated with different types of stratigraphic sequences (e.g., highstand, lowstand, or transgressive system tract).

Example:

1) Highstand deltaic facies models.

Activity 2. Provide empirical quantitative data on facies models

Provide empirical information in three-dimensions and within the context of genetic stratigraphy of variables important for the application of facies models to predicting reservoir distribution. Information to be acquired includes spatial frequencies of reservoir facies, geometries, interconnectedness, bounding surfaces, and other permeability barriers within genetic sequences.

Examples:

1) Studies of various Holocene depositional systems.

2) Outcrop studies of various depositional systems.

3) Subsurface studies of various depositional systems.

Area B. Identification of Intrafield Diagenetic Variability and Porosity Basement

Improvement in the ability to forecast reservoir quality and delineate diagenetic stratigraphic trapping mechanisms within a field through mapping and/or modeling vertical and lateral diagenetic patterns will increase production by exploiting untapped reservoirs. Using porosity basement forecasting, the economic depth limit of potential reservoirs within a field may be defined.

Activities

Activity 1. Modeling intrafield diagenetic variability

Modeling intrafield diagenetic variability can lead to the delineation of additional stratigraphic traps in a field through understanding diagenetically-controlled reservoir/seal relationships. Also the recognition of migration pathways or flow units through time will aid in understanding and predicting lateral reservoir quality distribution and the petroleum source for different reservoirs within a field.

Example:

1) Modeling of fields containing diagenetically trapped hydrocarbons.

2) Fingerprinting of oils to identify specific source rock.

Activity 2. Numerical porosity/permeability models

Development of numerical porosity/permeability models based on burial history (time, temperature, pressure) will aid in forecasting average reservoir quality at depth and in delineating the potential stratigraphic section within a field. This will help promote deeper development of fields, especially in fields where leases are held by shallower production.

Example:

1) Numerical porosity/permeability prediction models for different rock types (quartz arenites, litharenites, limestones, dolomites, etc.).

Activity 3. Statistical analysis of empirical reservoir-quality data bases

Statistical analysis of large, empirical reservoir-quality data bases (>10,000 data points) consisting of porosity, permeability, mineralogy, temperature, etc. from core and log analysis can be used to forecast average porosity and permeability.

Examples:

1) Develop regional empirical reservoir-quality data bases for major producing provinces.

2) Develop empirical methods for forecasting reservoir quality from large data bases.

Area C. Mesoscale to Macroscale Deformational Features

Faults and fractures are reservoir heterogeneities that overprint primary stratigraphic variations described in A and B. They may be sealing or non-sealing. They may provide avenues of fluid movement that strongly influence flow in primary or secondary recovery methods. There is a need to assess mesoscale (10^{-1} to 10^{2} m) deformational features (fractures, small faults, stylolites) as a function of regional stress history, structural style, and structural position and define their various impacts on fluid flow. Improved techniques should be developed for remote detection of fractures and extrapolation of fracture patterns from limited data, to map and/or predict the development of intrafield (secondary) faults, to determine the effective communication across these faults on a production time scale (e.g., 3-30 yr) and to evaluate the detailed geologic characteristics of these fault zones.

Activities

Activity 1. Determine the controls of stress and strain history and/or structural style on the nature, orientation, and intensity of deformational features for different reservoir rock types

Examples:

1) Perform mechanical tests on various reservoir rock types using a spectrum of burial and shallow crust stress, temperature and fluid content conditions.

2) Field study to assess intensity of fractures, small faults, and/or stylolites as a function of their resultant strain in different rock types.

Activity 2. Map fractures and/or in-situ stress using shear wave anisotropy, full-wave seismic, or other seismic techniques

Activity 3. Create and evaluate models to predict variations in strain and stress state, fault development, etc. as a function of structural position and structural style

Example:

1) Mechanical models (F/E or analytical) of representative structural forms for different structural styles using appropriate rheologies and mechanical stratigraphy.

2) Detailed outcrop and core studies of meso- and macroscale deformational features internal to a single major structure, integrated to stratigraphy, focusing on factors affecting reservoir flow properties. Acquisition and detailed description of cores taken through fault zones.

Activity 4. Improved techniques for recognition and mapping of secondary faults, especially using 3-D seismic techniques

Example:

1) Physical models to evaluate variations in secondary fault development as a function of structural style and mechanical stratigraphy.

Activity 5. Assess downhole tools designed to detect natural fracture development in a quantitative context

Example:

1) Calibration of wireline log fracture interpretation against core data.

Activity 6. Develop stochastic models for extrapolation of fracture data from core measurements to field-wide distribution

Example:

1) Application of fractal mathematics to fracture mapping.

Activity 7. Convert geological description of mesoscale discontinuities into quantitative flow parameters usable in reservoir modeling

Example:

1) Develop numerical model to simulate flow conditions in a rock body that is composed of a non-trivial matrix porosity and permeability plus distinct high- or low-flow discontinuities (faults or fractures).

Activity 8. Investigate reservoir partitioning effectiveness of intrafield faults as a function of fault type, displacement, and affected lithologies

Example:

1) Evaluate long-term production pressure variations between fault-separated compartments.

Area D. Numerical Geologic Modeling and Geoscientific Workstations

Develop forward, inverse, and statistical geologic models that incorporate existing empirical and interpretative data to predict reservoir attributes, distributions, and geometries from limited information. The models eventually should incorporate all geological aspects (including structural, stratigraphic, and diagenetic histories) that are important in controlling the ultimate character of reservoir plumbing systems. Presently, however, it is practical only to develop multiple models of different types, with the goal of merging them as they are developed. Model development should occur jointly and cooperatively with geological field studies designed to constrain and test the models so they are reasonably sensitive simulators of actual situations. These models should be implemented on geoscientific workstations with interactive graphics for user manipulation and assessment of geophysical and geological data as well as model output, and they should be driven by expert systems. Output of geological models should be designed for direct entry into reservoir simulators as the geologic description of reservoir plumbing systems.

Activities

Activity 1. Forward process-response geological models

Initially these should be developed as one- and two-dimensional dynamic simulations (2 yr), but then should be extended to full three-dimensional dynamic simulations (2-5 yr). Stratigraphic models are highest priority because structural controls on fluid flow of most fields may be defined by other means, and because development of stratigraphic models is crucial and must occur prior to 3-D dynamic fluid-flow and diagenetic models. Models should be deterministic in their approaches and goals, but will necessarily incorporate statistical aspects and geometric constraints in their initial developmental stages. Model development should at all times be integrated with field-based research on definition and quantification of petrophysical and fluid-flow properties of strata in different depositional and tectonic settings. Field-based studies will supply geologic constraints for model-development and tests of model predictions, thus ensuring that forward models reasonably simulate the real world. Output of the models should be in a form directly usable by reservoir simulators and they should create synthetic seismic profiles and well logs for comparison with field data.

Activity 2. Forward fluid-flow and diagenetic models

Basin- to field-scale dynamic fluid-flow and fluid-rock interaction (diagenetic) models should be developed and integrated with stratigraphic and structural models. They must incorporate kinetic and thermodynamic data as well as equations governing fluid flow through porous media.

Activity 3. Inverse geological models

As forward geological models are developed and verified by field studies, and therefore reasonable limits on frequencies, rates, and magnitudes of geologic processes become better established, inverse geological models should be developed. These will take observed data and then, working backward in time, reconstruct a family of geologically-constrained solutions of the processes responsible for forming the observed products. These should then be merged with forward models so that observational seismic, well log, and lithologic data may be compared with synthetically-generated model output of similar forms.

Activity 4. Geostatistical models

Where quantitative observations are insufficient, geostatistical models often offer the best prospect for inferring geology. Moreover, uncertainty factors are needed in geologic models that are incorporated in engineering simulations. Geostatistical parameters established by empirical means can provide a measure of reliability of data input into modeling. This is considered an intermediate step between nonquantitative, analog geologic models, and numerical geologic simulations. Examples of types of geological information that may require, at least initially, expression in statistical (population distribution) terms are facies substitutions, and frequencies and spacings of facies assemblages within genetic sequences.

Area E. Delineation and Understanding of Pressure Cells

Pressure cells of variable size are known to occur within sedimentary rocks. These cells are confined by low-permeability barriers, either parallel, oblique, or vertical to bedding. The cells may be either under- or over-pressured relative to normal hydrostatic pressures. The origin of the pressure cells and their relationship to traditional theories of hydrodynamic flow and to oil and gas fields are not completely known. Compaction, fluid-rock interactions, source-bed maturation, migration pathways, faults (fractures), and diagenesis are subjects which may contribute to the origin of pressure cells.

Activities

Activity 1. Collect data to better characterize pressure cells

Example:

1) From selected field areas, catalog pressure and fluid data related to pressure cells and pressure cell boundaries.

Activity 2. Determine the geometry and structure of the pressure cell boundaries

Example:

1) Identify fields which are a part of pressure cells; study core from cell boundaries within fields to determine physical characteristics of seals and relationship to oil and gas occurrence.

Activity 3. Relate local pressure conditions to regional hydrodynamic system

Area F. High-resolution Seismic Imaging for Field Definition

Forward and inverse geologic models that predict thinly bedded strata and new oil compartments within an existing field are only as good as the information they incorporate. The surface seismic reflection method along with borehole seismic techniques are becoming recognized as essential tools for accurate delineation of the framework of fields. These methods also have the potential for identifying compartment isolation that can occur during the production life of a field. This identification could provide the basis for new infill drilling and aid in maximizing the recovery of oil from the field. The research activities in this area will emphasize enhancing the resolution of seismic images, based on new processing methods and new data collection geometries, and the integration of these enhanced images with mechanical and elastic models of the field. This research plan also stresses the interpretation of multicomponent seismic data as the basis for estimating lithology, stress-fractures, and fluid content, and the integration of these data with existing geologic models using comprehensive geological and geophysical data over known fields.

Activities

Activity 1. Enhancement of vertical resolving power

Extending the effective bandwidth of the existing surface seismic technique is critical to improving definition of vertical and, to an extent, lateral elastic heterogeneity within a field. Variation of the elastic parameters over a field is one indicator of fluid distribution in the field. This research activity concentrates on acquisition and processing methods that can significantly improve resolution for lithologic, stratigraphic, and structural interpretation, as well as determination of fluid distribution.

Examples:

1) Develop cost-effective methods of data acquisition for extending bandwidth.

2) Improve deconvolution methods for removing the effects of the propagating wavelet and thereby improve reflectivity estimation.

Activity 2. Extend methodology for structural and stratigraphic interpretation of seismic data

Accurate integration of seismic data with geologic models will provide the basis for significant interdisciplinary advances in the identification of new oil-bearing compartments within existing fields. This activity will provide the research necessary to extend the knowledge base in this topic.

Examples:

1) Model 3-D seismic data based on a developing encyclopedia of structural and stratigraphic styles.

2) Determine seismic attributes that can be effectively correlated with characteristics of the associated geologic model.

Activity 3. Development of borehole seismic methods

In the surface seismic method, significant attenuation of the generated high-frequency seismic energy occurs within the near-surface. Borehole seismic methods, in which either or both the source or receivers are in the borehole, provide an opportunity to avoid this attenuation and to enhance, both vertically and laterally, the information that can be obtained about a field. The favorable geometric disposition of sources and receivers in borehole seismic methods also provides information relating to the reservoir framework that can be usefully combined with interpretations based on surface seismic data. Borehole-to-borehole electrical methods offer the potential for gaining a high degree of resolution of spatial variations in field characteristics. Likewise, surface and borehole gravity information can often place important constraints on interpretations of both surface and borehole seismic data.

Examples:

1) Development of downhole seismic sources, including the use of the drill bit as a source while drilling.

2) Improved imaging algorithms for 3-D vertical seismic profile (VSP) data.

3) Improved imaging algorithms for borehole-to-borehole data (e.g., extending the range of separation between boreholes over which the tomographic method technique can be effectively applied to delineate elastic parameters between boreholes).

Activity 4. Development of low-cost seismic methods

Considerable petroleum reserves remain to be recovered from shallow fields. In many cases these fields are small and historically could not economically support the use of seismic methods, even 2-D. This activity is intended to stimulate research in the development of novel ways of reducing the cost of both 2-D and 3-D seismic techniques (2-D for relatively small, shallow reservoirs, and 3-D to benefit economically from the vast amount of information available in properly imaged 3-D field data).

Examples:

1) Low-cost 2-D methods for shallow reservoirs.

2) Novel field methods for reducing collection time (e.g., reducing CMP-fold, use of large numbers of phones and distributed recording systems) for 3-D acquisition.

3) Improvements in the efficiency of imaging and noise-reduction algorithms in 3-D seismics.

4) Reduction in interpretation time through extended applications on interactive workstations.

Activity 5. Derivation of lithologic, stress-fracture, and fluid information from multicomponent seismic data

Considerable information concerning fracture density and orientation, fluid content, and fluid viscosity can be obtained by observing the relative propagation behavior of various acoustic wave types. These observations can be made by analyzing multicomponent seismic data (i.e., components of motion recorded in three orthogonal directions). The objective of this activity is to develop new methods of processing and analyzing such data so as to maximize information describing reservoir framework.

Examples:

1) Analysis of multicomponent data (e.g., analysis of amplitude versus reflection angle) to estimate lithologic parameters of thin beds.

2) Geostatistical methods for spatial interpolation and extrapolation of reservoir parameters measured in the borehole, through correlation with multicomponent seismic data.

3) Inversion of multicomponent data by exploiting shear-wave splitting to estimate fracture density and orientation with depth.

Activity 6. Improved imaging in structurally complex areas

Many fields lie beneath highly heterogeneous overburden. Severe travel-time distortions, for waves that travel through complex overburden, significantly increase the difficulty of producing adequate images of the structural and stratigraphic framework of an underlying field. Methods for improving the image quality of the reservoir interval in such situations must be developed if interpretation of new reservoir compartments is to be made in this setting.

Example:

1) Development of sophisticated methods for imaging limited intervals beneath complex overburden.

Activity 7. Acquisition of high-resolution,. 3-D surface seismic and borehole seismic data over selected, known type reservoirs

Neither the viability nor the benefits of incorporating the cross-disciplinary activities of geophysics and geological modeling can be effectively assessed without confirming the quality of results on actual data acquired over known reservoirs of different types. Proper assessment of our ability to predict field framework requires acquisition of a comprehensive set of geologic, geophysical, and engineering data over known fields.

Example:

1) Collect and process surface and borehole seismic data, along with geological and engineering data, over various known reservoir types; e.g., fluvial sandstones, shoal carbonates.

Area G. Improved Logging Techniques for Reservoir Delineation

Wireline logs are the most abundant form of subsurface information and can provide critical data for reservoir imaging and definition and important information on fluid properties. Well logs reveal the nature of structure (characterize fractures and faults), stratigraphy (characterize bedding and their correlation), lithology (composition, texture, chemical, and acoustic properties, pore space), and formation fluids (relative saturations and flow). Logs are a vital link between geology, engineering, and geophysics and provide information beyond what is routinely extracted from cores, e.g., detecting fundamental rock properties such as elemental composition. Optimum tool selection and processing is needed to maximize information that can facilitate multi-disciplinary efforts toward establishing reservoir properties.

Activities

Activity 1. Integrate new logs into interpretations of reservoir and define new applications

Develop and refine applications of pattern recognition, autocorrelation, forward modeling, and expert systems to develop refined, integrated interpretations of the reservoir and associated strata using new improved logging suites. Methods in numerical inversion and geostatistical analysis (electrofacies) are needed to define consistent and geologically significant classification of log response. Applications of new tools for use in reservoir frameworks needs to be supported.

Examples:

1) Investigate applications of natural gamma ray spectrolog as a tool to enhance geological interpretation to improve reservoir definition.

2) Examine high-resolution dipmeter and new high-resolution digital borehole imaging logs for use in detailed characterization of stratification and porosity types such as fractures and vugs.

3) Further investigations are needed in the use of the borehole gravimeter in cased holes for density measurements.

4) Properties of rock and fluids beyond the borehole need to be addressed using promising logs such as the borehole radar (measuring volume of various lithologies), and borehole-to- borehole resistivity to characterize pore fluids.

5) Permeability logging and detection of flow are urgent needs to characterize the reservoir as a dynamic system as fluids are produced.

Activity 2. Develop new or refined applications of old logs to solve long-standing problems

Old logs provide varied types and quality of information suited for reservoir description. Common log suites at least distinguish reservoir from nonreservoir strata and provide information on the geometrical arrangement and interconnectedness of reservoir facies. Response must be standardized and sharpened, if possible, in order for this information to be incorporated into improved re-intepretations.

Examples:

1) Continued research in mathematical blocking and deconvolution functions is necessary to maximize information from old logs.

Activity 3. Develop optimum logging suites using expert systems tailoring results to specific reservoir types and their inherent problems

Logging conditions vary considerably due to borehole environment, reservoir characteristics and fluids, structure, and depth. Furthermore, the problems of reservoir development require specific types of logs to provide the most precise and direct solutions. Knowledge-based expert systems could readily assist in providing optimum well selection and analytical approaches.

Example:

1) Build data base of reservoir description, problems, and tool capabilities for reservoirs in question.

Activity 4. Identify sites to demonstrate and test tools and methods of interpretation

Control sites are needed to test tool designs and processing to maximize information on reservoir framework. Results must also be compared and integrated with other forms of data, e.g., cores, seismic, well tests.

Example:

1) Identify sites in and near reservoirs with special problems or well-known conditions for extensive testing of tools.

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
A. Development and Application of Empirically Derived Four-Dimensional Stratigraphic Models									
1. 4-D genetic stratigraphic and sequence stratigraphic characterization of facies models	1	X							
a. Highstand deltaic facies models							X		
2. Provide empirical quantitative data on facies models	1	X							
a. Studies of various Holocene depositional systems							X		
b. Outcrop studies of various depositional systems							X		
c. Subsurface studies of various depositional systems							X		
B. Identification of Intrafield Diagenetic Variability and Porosity Basement									
1. Modeling intrafield diagenetic variability	1	X							
a. Modeling of field containing diagenetically trapped hydrocarbons							X		
b. Fingerprinting of oils to identify specific source rocks							X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
2. Numerical porosity/permeability models	2	X							
a. Numerical porosity/permeability prediction models for different rock types							X		
3. Statistical analysis of empirical reservoir-quality data bases	2	X							
a. Regional empirical reservoir-quality data bases for major producing provinces							X		
b. Empirical methods for forecasting reservoir quality from large data bases							X		
C. Mesoscale to Macroscale Deformational Features									
1. Determine the controls of stress and strain history and/or structural style on the nature, orientation, and intensity of deformational features for different reservoir rock types	1	X							
a. Perform mechanical tests on various reservoir rock types using a spectrum of burial and shallow crust stress, temperature, and fluid content conditions							X		

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
b. Field study to assess intensity of fractures, small faults, and/or stylolites as a function of their resultant strain in different rock types							X		
2. Mapping fractures and/or in-situ stress using shear wave anisotropy, full-wave seismic, or other seismic techniques	2	X					X		
3. Create and evaluate models to predict variations in strain and stress state, fault development, etc., as a function of structural position and structural style	2	X							
a. Mechanical models of representative structural forms for different structural styles using appropriate rheologies and mechanical stratigraphy							X		
b. Detailed outcrop and core studies of deformational features internal to a single major structure							X		
4. Improved techniques for early recognition and mapping of secondary faults, especially using 3-D seismic	2	X					X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS → ACTIVITIES → EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
5. Assess downhole tools designed to detect natural fracture development in a quantitative context	3	X							
a. Calibration of wireline log fracture interpretation against core data							X		
6. Develop stochastic models for extrapolation of fracture data from core measurements to field-wide distribution	3	X							
a. Application of fractal mathematics to fracture mapping							X		
7. Convert geological description of mesoscale discontinuities into quantitative flow parameters usable in reservoir modeling	1	X							
a. Develop numerical model to simulate flow conditions in a rock body that is composed of a non-trivial matrix porosity and permeability plus distinct high or low flow discontinuities (fractures or faults)							X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH (AREAS / ACTIVITIES / EXAMPLE PROJECT)	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
8. Investigate reservoir partitioning effectiveness of intrafield faults as a function of fault type, displacement, and affected lithologies	1		X						
a. Evaluate long-term production pressure variations between fault-separated compartments							X		
D. Numerical Geologic Modeling and Geoscientific Workstations									
1. Forward process-response geological models	1	X					X		
2. Forward fluid-flow and diagenetic models	2		X				X		
3. Inverse geological models	1	X					X		
4. Geostatistical models	3	X					X		
E. Delineation and Understanding of Pressure Cells									
1. Collect data to improve our general understanding of pressure cells	2	X							
a. Catalog pressure and fluid data related to pressure cells and cell boundaries from selected field areas							X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
2. Determine the geometry and structure of pressure cell boundaries	1	X							
a. Study fields which are part of pressure cells to define geometry and nature of cell boundaries							X		
3. Relate local pressure conditions to regional hydrodynamic system	3	X					X		
F. High-Resolution Seismic Imaging for Field Definition									
1. Enhancement of vertical resolving power	1	X							
a. Develop cost-effective methods of data acquisition for extending bandwidth							X		
b. Improve deconvolution methods for removal of the effects of the propagating wavelet and thereby improve reflectivity estimation							X		
2. Extend methodology for structural and stratigraphic interpretation of seismic data	1	X							
a. Model 3-D seismic data based on a developing encyclopedia of structural styles							X		

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
b. Determine seismic attributes that can be correlated with characteristics of the associated geologic model							X		
3. Development of borehole seismic methods	1	X							
a. Development of downhole seismic sources, including the use of the drill bit as a source while drilling							X		
b. Improved imaging algorithms for 3-D vertical seismic profile (VSP) data							X		
c. Improved imaging algorithms for borehole-to-borehole data							X		
4. Development of low-cost seismic methods	2	X							
a. Low-cost 2-D methods for shallow reservoirs							X		
b. Novel field methods for reducing collection time for 3-D acquisition							X		
c. Improvements in the efficiency of imaging and noise-reduction algorithms in 3-D seismic							X		
d. Reduction in interpretation time through extended applications on interactive workstations							X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
5. Derivation of lithologic, stress-fracture, and fluid information from multicomponent seismic data	1	X							
a. Analysis of multicomponent data to estimate lithologic parameters of thin beds							X		
b. Geostatistical methods for spatial interpolation and extrapolation of reservoir parameters measured in the borehole, through correlation with multicomponent seismic data							X		
c. Inversion of multicomponent data by exploiting shear-wave splitting to estimate fracture density and orientation with depth							X		
6. Improved imaging in structurally complex areas	3	X							
a. Development of sophisticated methods for imaging of limited intervals beneath complex overburden							X		

*1,2, or 3

RESEARCH (AREAS / ACTIVITIES / EXAMPLE PROJECT)	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
7. Acquisition of high-resolution, 3-D surface seismic and borehole seismic data over selected, known type reservoirs	2		X						
a. Collect and process surface and borehole seismic data along with geological and engineering data over known reservoir types							X		
G. Improved Logging Techniques for Reservoir Delineation									
1. Integrate new logs into interpretations of reservoir and define new applications	2	X							
a. Investigate applications of natural gamma-ray spectrolog as a tool to enhance reservoir definition							X		
b. Examine high-resolution dipmeter and new high-resolution digital borehole imaging logs for use in detailed characterization of stratification and porosity types							X		
c. Further investigations in the use of the borehole gravimeter in cased holes for density measurement							X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH (AREAS / ACTIVITIES / EXAMPLE PROJECT)	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
d. Investigate use of borehole radar and borehole-to-borehole resistivity to characterize rock and fluid types							X		
e. Investigation of permeability logging and detection of flow							X		
2. Develop new and refined applications of old logs to solve long-standing problems	2	X							
a. Continued research in mathematical blocking and deconvolution functions to maximize information from old logs							X		
b. Calibration of old logs with modern tools							X		
3. Develop optimum logging suites using expert systems tailoring results to specific reservoir types and their inherent problems	3	X							
a. Build data base of reservoir description, problems, and tool capabilities for selected reservoirs							X		

*1,2, or 3

RESEARCH AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
4. Identify sites to demonstrate and test tools and methods of interpretation	3	X							
a. Identify sites in or near reservoirs with special problems or well-known conditions for testing of tools							X		

*1,2, or 3

RESERVOIR CHARACTERIZATION

Geoscience Institute
Technical Subcommittee Report

for

U.S. Department of Energy
Office of Fossil Energy

Prepared by

Noel Tyler, University of Texas at Austin*
Tom Hewett, Chevron Oil Field Research Company*
Bill Iverson, University of Wyoming
Hans Jahns, Exxon Production Research Company
Andre Journel, Stanford University
S. C. Leininger, Mobil Exploration and Producing Services, Inc.
Rob L. Mathis, Shell Western E&P Inc.
John A. McDonald, University of Houston
Donald F. Oltz, Illinois State Geological Survey
Ronald J. Robinson, Texaco Houston Research Center

*Subcommittee Co-chairmen

RESERVOIR CHARACTERIZATION

PROBLEM DEFINITION

Recovery of oil and gas from complex reservoirs is inefficient because our understanding of the architecture of sediments is inadequate to explain and predict internal variability and the paths of fluid flow in the reservoir. Wells drilled on conventional surface geometric grids result in hydrocarbon-bearing zones remaining uncontacted or only partially contacted during implemented recovery programs. Thus, a potentially large volume of oil and gas remains in uncontacted or partly drained compartments. Furthermore, permeability barriers and lateral and vertical variation in petrophysical rock properties prevent uniform sweep by supplemental extraction technologies. Substantial hydrocarbons, potentially recoverable by secondary and tertiary programs, remain bypassed in the reservoir.

The problem to be resolved is to develop a greater understanding of reservoir heterogeneity through geological, engineering, and geophysical techniques, to quantify that variability through deterministic or stochastic geostatistical methods, and deploy that understanding to improve hydrocarbon recovery. Knowledge of the three-dimensional distribution and variability of physical rock properties would allow optimum well placement, well completions, and extraction techniques to be employed resulting in increased recovery of mobile oil, residual oil, and gas.

BACKGROUND AND STATUS

The urgent need for improved reservoir characterization is most readily witnessed in the large number of failed tertiary recovery projects. The most commonly cited reason for failure is insufficient geologic characterization of the reservoir due to heterogeneities. While geologists have routinely studied modern and ancient sediments, their investigations have been directed primarily to the vertical profile and ultimately to interpretation of environment of deposition. Consequently, our understanding of lateral variability in reservoirs is limited. Further, quantification of this variability is largely lacking and simulation of oversimplified reservoir properties overestimates conventional recovery and undervalues the potential for extended conventional and enhanced recovery. Engineering descriptors such as pressure testing and tracers are applied with an imprecise understanding of the geologic framework, and thus the predictability and extrapolation potential of these techniques is limited.

The tools required for reservoir characterization are, to a large extent, available. A greater need is for improved use of existing techniques utilized in multidisciplinary studies. In addition to development of tools and techniques for improved reservoir characterization, what is required is a series of detailed integrated outcrop and reservoir studies that will serve as type examples for ongoing research.

RESEARCH APPROACH

Reservoir characterization is a problem that spans geological, engineering, geophysical, and statistical disciplines and, furthermore, influences all aspects of field exploitation from well completion practice, well stimulation, performance prediction to advanced extraction technologies. Improved recovery of remaining hydrocarbons will require significant advances in our ability to characterize reservoirs and demands integrated, multidisciplinary research endeavors. Deterministic architectural and petrophysical modeling of representative analogous outcrops coupled with parallel multidisciplinary studies of similar reservoir types in the subsurface offer immediate benefit in the form of improved understanding of compartmentalization and paths of fluid flow. Improved statistical description of rock properties and their variability within this framework facilitates performance prediction within the candidate reservoir and extension of results to other analogous reservoir types. Improved geophysical and engineering (tracers and pressure transient analysis) techniques incorporated with geologic description and interpretation will improve our ability to characterize interwell areas and foster improved hydrocarbon recovery.

RESEARCH AREAS

A. Recognition and Quantification of Reservoir Heterogeneity

Activities

Activity 1. Studies of heterogeneity of reservoir heterogeneity in outcrop

Accurate quantification of heterogeneity in complex reservoir systems can only be achieved if control cases exist that provide the geologic ground truth for calibration of hypothetical or geostatistically simulated interwell heterogeneity estimates. Detailed outcrop mapping can provide the critical quantitative data needed to assist in modeling studies of subsurface reservoir heterogeneity where the data set is inherently less complete. Outcrop study areas should be selected such that the geologic setting is well controlled, and such that the facies tracts studied are as closely comparable to their reservoir counterparts as possible. In order to be of maximum benefit, outcrop studies must be quantitatively oriented. Basic data should include dimensions of depositional and diagenetic facies, as well as rock fabric/petrophysical properties and porosity/permeability data for each facies. Areas of basic research include (1) outcrop studies in all major depositional settings, prioritized to their respective potential in terms of the defined unrecovered oil volumes in equivalent reservoirs, (2) geostatistical studies that attempt to recreate true (outcrop) heterogeneity using controlled selected portions of the complete outcrop data set, and (3) integration of outcrop heterogeneity models with their reservoir counterparts in order to evaluate the predictive capabilities of outcrop-based reservoir heterogeneity models.

a. Selection of outcrop reservoir equivalents.

b. Establish systematic sampling procedures for outcrop data commensurate with the type of data obtained from the subsurface.

c. Detailed mapping, various outcrops.

d. Statistical analyses of data.

Activity 2. Studies of heterogeneity in modern sediments

Studies of modern siliciclastic and carbonate sediments have concentrated on sedimentary processes, vertical character, constructional topography, and early diagenesis. The results of these modern studies permit the interpretation of depositional environments of ancient sediments represented in cores and wireline logs from reservoirs. However, little effort has been made to document geometries and the subtle variations in grain type, size, and packing between and within depositional facies, factors which ultimately control porosity and permeability, horizontal and vertical heterogeneity, and fluid-flow characteristics. Large numbers of short, closely spaced, shallow cores from known depositional environments can be readily obtained. Detailed mapping of sediment patterns based on collection and description of these closely spaced cores would aid in the interpretation of well-to-well heterogeneity to be expected within a hydrocarbon reservoir. Statistical analyses of the resulting patterns obtained using various well spacings would provide guides to the determination of distribution of reservoir flow units between wells.

a. Compilation of sediment patterns with respect to potential hydrocarbon flow paths and barriers.

b. Detailed mapping of sediment patterns.

c. Statistical analyses of data.

Activity 3. Develop rapid subsurface and laboratory methods to identify heterogeneity types

Unraveling reservoir heterogeneity in the subsurface environment, where only very small samples of the reservoir rock are available as cores and where most (and in some cases all) boreholes were not cored, is a major task of reservoir characterization. Development of reliable methods to identify types of heterogeneity with subsurface data, especially reliable methods of calibrating core data with wireline logs, is a prerequisite to mapping the three-dimensional geometry of reservoir flow units.

a. Develop criteria for recognizing geological flow units in cores.

b. Computer applications for describing pore geometries and geologic facies.

c. Calibration of rock facies and fabrics with wireline log response.

d. Calibration of geophysical interpretation with geologic description.

Activity 4. Determine the impact of geologic heterogeneity on reservoir performance

Most geological formations in hydrocarbon reservoirs exhibit a high degree of heterogeneity. Major variations in production indicated in wells only hundreds of feet apart are presumed to be the result of this heterogeneity, although variations in completion techniques must also be considered. The degree of geological control on reservoir development varies significantly depending on the lithology, depositional setting, burial diagenesis, and structural complexity. In order to document the impact of geological heterogeneity on reservoir production, detailed rock descriptions must be closely correlated with engineering and production data. Computer simulation models can most effectively integrate geologic heterogeneity and production history of a reservoir.

a. Compare field production history with geologic descriptions.

b. Integrate geologic heterogeneity into computer simulation of production history.

Activity 5. Develop methods of integrating diagenetic effects into reservoir models

It is well documented that post-depositional changes in mineralogy and fabric (that is, diagenesis) can have profound effects on reservoir porosity and permeability. Studies of the diagenesis of the the reservoir sequence are thus basic to definitive reservoir modeling. Fundamental questions to be addressed are the (1) controls on the extent of diagenetic alteration of the reservoir sequence and (2) effects of diagenesis on pore geometries and distribution.

Detailed petrographic examination forms the basis for understanding the number, sequence, extent, and timing of diagenetic events and their relationships with reservoir porosity and permeability. Although normal transmitted-light microscopy is the fundamental tool in this analysis, this technique must almost always be supplemented by cathodoluminescence, fluorescence, scanning electron, and reflected-light microscopy.

Trace element and isotope geochemistry provide important additional data which constrain the origin and age of depositional and diagenetic mineral phases. Geochemical data may permit recognition of otherwise unrecognizable variations in reservoir lithology that can be crucial to identifying the best reservoir zones.

a. Effect of dissolution at all scales from karsting to fabric selective dissolution.

b. Origin and distribution of evaporite minerals and carbonate cements.

Activity 6. Determine geologic controls on residual oil

Determination of residual oil volume is critical to assessing the potential for recovery of remaining mobile oil by infill drilling. Strategic siting of infill wells further requires knowledge of variations in residual oil saturation (ROS) throughout the reservoir. This requires measurement of ROS for each diagenetic or depositional facies in the reservoir.

Once depositional and diagenetic facies have been identified, residual oil saturations can be measured directly from core by mercury injection techniques. Care must be taken to select core that is minimally altered from its original state. Variations in ROS can then be related to geologic processes and mapped throughout the reservoir.

a. Measure pore geometries and residual oil for various lithofacies and diagenetic facies types.

Activity 7. Develop catalog from outcrop and subsurface studies of styles of reservoir heterogeneity and production response

A useful product of these studies will be a compilation of all studies into a folio series. Sediment architecture and relation to production will be a key focus of the publication, as will techniques and strategies for reservoir description.

Activity 8. Develop improved methods for using production data to locate remaining hydrocarbons

Production history often most accurately describes the distribution of remaining hydrocarbons, assuming completion differences can be compensated. This activity envisions the development of new methodology for the interpretation of production data in terms of the distribution and character of remaining oil and gas in reservoirs.

B. Research at the Interwell Scale

Develop techniques in key reservoir types using integrated multidisciplinary research teams for processing and interpreting subsurface data in the reservoir framework at the interwell scale.

Activities

Activity 1. Well/well seismology (1000's of Hz)

Due to the one-way travel path, borehole coupling of the source and receivers, and the resultant lower attenuation, well-to-well tomography offers the hope for high-resolution heterogeneity mapping. The field application, special computer processing, and interpretation of tomographic data should be conducted when an effective downhole source and multi-element receiver array are available from the geophysical industry. The treatment of the tomographic model as an increasing approximation to the real earth from straight-ray tomography to kinked-ray modeling to finite-difference acoustical modeling to elastic modeling are subjects of the basic research.

a. Evaluate applicability of crosswell techniques for reservoir geometry and continuity.

b. Develop tomographic and reflection imaging techniques for quantitative reservoir description.

c. Enhance applicability of elastic waves for fluid detection.

d. Analyze multiple wells for three-dimensional imaging.

Activity 2. Well/surface seismology (100's of Hz)

Vertical seismic profiles (VSP) have the potential of substantially increasing reservoir resolution. But this has rarely been proven. New technology is needed to perfect the VSP technique, particularly in the area of reverse VSP (downhole sources), and analysis of compressional and shear wave sources.

a. Case studies demonstrating substantial (a full order of magnitude) improvement in reservoir resolution of targeted reservoir types.

b. Complete use of 3-component offset VSP for wavefield decomposition into P-P, P-S, S-S, and verification of amplitude vs. offset responses.

c. Measurements while drilling (controlled transmission from bit to surface and reversed VSP.

Activity 3. 3-D surface/surface seismology

The surface seismic method is well tested as a technique for determining structure at depth; it is not well tested for determining lithology or fluid content. The basic problem is of generating high frequency compressional and shear waves at the surface and recording as high a frequency as possible in the signals returned to the surface. The near surface (the weathered layer) is a very efficient filter of high frequencies for both the downgoing and the upcoming waves. In addition, if the surface has a varying elevation, it also has an efficient spatial filter of high frequencies. Hence, experiments designed to evaluate surface seismic methods for reservoir description must be carried out, initially, in fields with minimal topographic relief and no known weathering problem. Once the three-dimensional distribution of reservoir rocks and fluids has been determined in a simple field, this research effort will move to fields with increasing near-surface complexity.

At each location different "tools" will be evaluated; namely, compressional and shear mechanical sources and 1-, 2-, and 3-component detectors. All of these experiments will be carried out in three dimensions, that is, with sources and receivers spread over the area of the field and its surrounding non-producing areas.

a. Select three relatively small fields with the following characteristics:

   1) Minimal topographic relief and no known weathering problems; known good seismic data.

2) Minimal topographic relief and known weathering problems; known good seismic after correcting for weathering.

3) Topographic relief and known weathering problems; known good seismic after correcting for topography and weathering.

b. Evaluate in 1a) above:

1) High frequency compressional sources.

2) High frequency shear sources.

3) 1-, 2-, and 3-component detectors.

c. Whichever of the techniques are successful in determining the distribution of fluids and reservoir rocks in 1a) apply successively to the fields in 1b) and 1c).

Activity 4. Tracers and pressure transient tests

The quantification of reservoir heterogeneities by tracer flow experiments holds considerable promise but is also plagued by practical problems. The residence time distribution measured in field experiments contains much valuable information if it can be interpreted using reasonable models of the pore space between injection and production wells. However, such experiments tend to be very expensive and time consuming. Extensive sampling and analytical programs are required to get reasonable data. Uniqueness of models is always questionable if not impossible to determine. Best results have been obtained in small pilots (close well spacing) in formations with minor heterogeneities. Residual fluid saturations have been uncovered in some cases using positioning tracers.

In certain situations, single-point injection production tests may be effective in measuring reservoir heterogeneity. Especially in carbonate formations and/or naturally fractured pore systems, the shape of the tracer production profiles may produce valuable information on residence time/mass transfer properties of the rock. Test time and sampling requirements are much more practical, since the volume of pore space sampled is controlled by injected fluid volume rather than interwell spacing. Well-proven methods for measuring residual saturations are available which are independent of heterogeneity in sandstones and some carbonates. These methods can be applied to existing reservoirs at reasonable cost to improve the characterization of important reservoir types.

The problems associated with interpreting pressure transient data are well documented. Nevertheless, the method is widely accepted as a primary tool for formation evaluation. Modern downhole instrumentation allows precise recording of low-level signals at moderate cost. Both single-well and well-to-well (interference, pulse-test) applications can give relatively deep investigations quickly. The theoretical literature on interpretations of test results is extensive; faulting multiple layers, natural fractures, complex porosity systems, and other types of heterogeneity can be identified and in some cases quantitatively described. The algorithms for interpretation have been programmed for all levels of computer and are more or less available to academic as well as commercial researchers.

a. Well-to-well tracer tests on targeted reservoir types.

b. Single-point tracer tests on targeted reservoir types.

c. Pressure transient tests on targeted reservoir types.

An ideal research effort utilizing tracers and pressure tests would be structured as follows:

1) Identify a set of qualified groups within the consortium to advance trace and pressure transient test technology.

   a) Groups with theoretical/interpretation capabilities.

   b) Potential field-test crews.

2) Select a set of fields for research applications, preferably in coordination with other types of reservoir description tests.

3) Assign specific tasks to members of the competent theory/test groups; monitor progress in field work and theoretical development; review results and recommend extensions to other field projects.

4) Transfer improved technology to other academic groups and industry.

Activity 5. Horizontal wells

With new drilling technology providing horizontal wells, the full potential of such wells has yet to be realized in reservoir evaluation. Many fundamental experiments need to be researched in this new wellbore environment.

a. Example projects

   1) Continuous coring horizontally in a producing reservoir.

   2) Analysis of transient well tests in horizontal wells.

   3) "Vertical" Seismic Profiling in horizontal wells.

   4) Crosswell studies from horizontal wells.

C. Research on Borehole Measurements

Develop techniques in key reservoir types using integrated multidisciplinary research teams for processing and interpreting subsurface data in the reservoir framework at the single well scale. Such measurements address wellbore conditions at the microscale of rock and fluid properties.

Activities

Activity 1. Rock and fluid properties derived from logs

Well logs are the fundamental tools for determining in-situ rock and fluid properties. Although many logs are presently available, there is a need for new and improved measurements.

a. Permeability measured from logs with good vertical resolution (1 ft) at a reasonable logging speed, in any formation, without having to take cores or conduct long production tests.

b. Deeper penetration logs that reach many tens of feet into the formation and measure unaltered rock and fluid properties.

c. Cased-hole logs that reliably determine fluid properties behind steel casing, irrespective of the type of fluids that are present.

d. In-situ determination of fluid properties which are a function of their interaction with rock type, such as grain wettability, capillarity, and multiphase relative permeability.

e. Seismic logs that measure true elastic properties in slow and fast formations and reach beyond the invaded formation.

Activity 2. Predictive geochemistry is a new field rapidly expanding from inorganic reaction kinetics to include organic species. Using chemical information gathered from the well, this tool can be used to model the chemical reaction paths at the skin surface and, to a limited extent, predict chemistries away from the borehole (including rate and time). This tool is an attempt to integrate engineering and geochemistry by predicting formation damage based on the characteristics of the individual reservoir.

a. Rock fluid interactions - It is understood that different age/diagenetic effects on formations will cause variations in chemical reactions at the wellbore. Thus, stimulation (and completion) practices need to be modeled for prediction. Similarly, depletion practices can be detrimental: precipitation of asphaltenes in a reservoir, movement of sulfates, sanding, etc. Some understanding of and predictability of those processes as well as oil/formation-water interactions with the rock matrix (relative permeability, wettability, capillarity under reservoir conditions) need to be pursued. These types of studies include multiphase core-flow experiments at reservoir temperature and pressure; measurements of compatibility of injected fluids with the formation.

b. Fingerprinting of oils is important to reservoir characterization for identification of commingling, source variation, and, to a certain extent, compartmentalization. The chemistry of the oil will change within the reservoir as it is being produced, thereby giving an indication of compartmentalization.

c. Water chemistry - The composition of in-situ reservoir fluids, particularly formation brines sampled downhole, is extremely important in recognizing and controlling adverse chemical reactions. Operators often reinject produced water with no understanding of how that water will react in different formations.

Activity 3. Rock and fluid properties derived from core

Improvements in acquisition and interpretation of data obtained from core will aid in the understanding of fluid flow through the formation near the wellbore. Naturally occurring diagenetic components can severely affect the productivity of the facies within the reservoir. Stress/strain analyses will help predict natural fracture trends as well as predict the direction of hydraulic fractures.

a. Example projects

1) Distribution and type of diagenetic components, especially clays.

2) Stress/strain quantification and prediction.

D. Integration of Numerical and Interpretive Information into a Quantitative Model of Reservoir Properties and Fluids

The ultimate goals of reservoir characterization are to describe in detail the spatial distribution of porosity and permeability and especially fluid saturations. This information is used to construct more accurate models of reservoir performance. These rock and fluid properties can be measured directly only at well locations, which provide a numerical data base. However, to characterize internal reservoir properties in detail that is sufficient for improving conventional or enhanced oil recovery strategies, the interwell patterns in these properties must also be estimated. This can be accomplished through interpretation of semiquantitative geologic and geophysical data together with the numerical data. Such integration and its eventual use in reservoir simulators are hampered by the following problems.

- The relationship between rock/fluid properties and the semiquantitative geologic/geophysical characteristics is often highly uncertain and remains poorly understood.

- Even if such a relationship is known, the interwell geometry of rock facies or flow units is typically difficult to predict at a high level of certainty owing to our limited understanding of complex depositional and/or structural conditions.

- Even if the interwell permeability and porosity patterns can be mapped in detail, no practical methods exist for scaling these data up to simulator blocks without risking loss of important information.

In many cases, the above problems can be partly resolved with conventional methods; however, the uncertainties inherent to the basic data and to the geologic/geophysical interpretations typically remain. Such uncertainty, if left unquantified, reduces the usefulness of the reservoir description and discourages effective integration of the description into simulation models. In the outline below, geostatistical and stochastic methods are included as a means of handling the uncertainty problem and of bridging the gap between the semiquantitative reservoir description and the reservoir simulator.

Activities

Activity 1. Develop methods for estimating rock and fluid properties from geologic, engineering, and geophysical data. (Most of this research should be integrated with outcrop studies.)

a. Perform integrated field studies in which geologists, engineers, geostatisticians, and petrophysicists interact closely to identify interrelationships between properties of reservoir rocks and fluids (e.g., porosity, permeability, and saturation) and geologic, geophysical, and petrophysical characteristics.

b. Adapt and perfect geostatistical methods for quantifying the uncertainty of estimating properties of reservoir rocks and fluids based on geologic, geophysical, and petrophysical characteristics.

c. Develop methods for relating seismic measurements to reservoir properties.

   1) Perform research on calibration of seismic velocities and amplitudes to porosity and permeability as inferred from neighboring well data.

   2) Generate permeability and porosity spatial distributions using seismic information.

Activity 2. Develop methods for inferring and quantifying continuity and anisotropy of flow properties, with special attention to the extreme high and low permeability reservoir facies

a. From outcrop data and/or geological interpretive drawings, infer statistical distributions of geometric characteristics of geological flow units. Relate these statistics and characteristics to the environments of deposition such that the results can be applied to subsurface studies in a predictive mode.

b. Develop algorithms for stochastically generating many different spatial images of the geological flow units such that each image honors the data and the spatial statistics. Test whether the stochastic images adequately approximate actual field heterogeneity.

c. Perform detailed geostatistical and flow modeling studies of outcrop and subsurface rocks to determine the level of detail needed in the description of reservoir heterogeneity.

d. Develop geostatistical approaches focusing on modeling spatial connectivity at extreme permeability values (flow barriers and high-permeability paths). Determine whether characterization of connectivity of the extremes is adequate for determining reservoir flow conditions.

Activity 3. Develop interactive computer graphics for visualization and editing of 3-D spatial distribution of reservoir attributes

a. Develop workstation-based software that will allow geoscientists to interactively compose 3-D distributions of geologic facies and/or rock properties, including slicing in any direction and "exploded" diagrams showing internal geometries.

b. Develop software for interactively editing the above.

Activity 4. Develop methods for quantifying, processing, and combining information from different sources

a. Develop standard methods of quantifying semiquantitative geologic and geophysical data to produce quantitative 3-D geologic models.

b. Develop techniques for stochastic modeling of reservoir attributes including development of algorithms for fast 3-D multiple attribute conditional simulation.

c. Adapt and perfect geostatistical methods for quantifying the uncertainty of estimating properties of reservoir rocks and fluids based on geologic, geophysical, and petrophysical characteristics.

Activity 5. Develop methods for scaling description of reservoir permeability up to simulator blocks

a. Determine appropriate techniques for calculating average absolute and relative permeabilities to be assigned to a simulator block as a function of block size, connectivity of the extremes, statistical attributes, and/or any other measurable properties.

b. Develop interactive software to perform the above through the use of stochastic distributions (images) of reservoir attributes and the use of interactive geologic workstation (i.e., estimate the 3-D distribution of permeability and its uncertainty using the interactive geologic workstation and stochastic analysis). Determine appropriate simulator block sizes that are consistent with the concept of a representative elementary volume and CPU/hardware constraints; and calculate the appropriate "block-effective" values of absolute and relative permeability for each block.

E. Fractured Reservoirs

Our ability to predict the performance of fractured reservoirs is hampered by incomplete information about the geometry of fracture networks at the interwell scale, the fluid flow dynamics within the fracture, the effects of the state of stress on the flow characteristics of individual fractures, and the accessibility of matrix blocks between fractures by fluids injected at wells intersecting fractures.

Activities

Activity 1. Develop geophysical methods for characterizing fractures

Seismic methods for identifying fracture locations and orientations. There is strong evidence that fractured rocks can be considered to be anisotropic media. In general, this means that certain physical properties vary within the rock depending upon which direction it is measured. Unfortunately, it is difficult to put quantitative values on fracture dependent anisotropy in real rocks. As always, assumptions made from surface expressions of fractures may be entirely wrong in the subsurface.

The two physical properties that are directly affected by oriented cracks are seismic velocity (both compressional and shear) and seismic amplitude. The effects of fracture anisotropy on these physical parameters should be quantified. The best way to do this is to use physical models of oriented fractures of differing fracture densities and with different materials and fluids in the cracks. These experiments will be carried out in both the transmission and reflection mode.

Then, a site should be selected without complicated topography in which a series of experiments can be carried out in both the transmission (crosshole tomography) and reflection (3-D surface/surface seismic) modes.

a. Determine fracture densities and fracture fluid content that determine anisotropy for fractured rocks.

b. Determine quantitatively the effects on seismic velocities and amplitudes of the various fracture densities deemed in 1 (above) to be anisotropic.

c. Select a site in which fracture patterns are well documented both at the surface and in the subsurface and have fracture densities that are deemed anisotropic under 1 (above).

d. Carry out a series of experiments using areal (3-D) surface seismic and crosshole seismic through the oriented fractures.

e. Analyze these experiments to see if seismic methods can be of practical application in determining unknown fracture patterns and orientations.

f. Demonstrate the use of shear wave attenuation to map the location and orientation of fractures.

g. Determine the effect of fluids on the seismic response of individual and multiple fractures.

h. Determine the electrical characteristics of fluid-filled fractures and develop methods for the electrically mapping fracture systems.

Activity 2. Determine the statistical characteristics of fracture networks and evaluate correlation of fracture array orientation, size, and density between outcrop and the subsurface

a. Conduct outcrop studies to map fracture networks and determine the statistics of fracture lengths and interconnectivity.

b. Develop methods for determining in situ the distribution of fracture apertures.

c. Horizontal wells for direct measurement of fracture character.

d. Determination of the frequency distribution of intact block sizes (bounded by fracture and bedding).

Activity 3. Determine the effects of stress and strain on the characteristics of fracture networks

a. Develop models for predicting fracture orientation from a knowledge of the regional stress field.

b. Develop models relating the effects of structure and lithology on the resulting fracture characteristics.

c. Investigate the effects of the state of stress on the flow characteristics of fractures, including the fracture conductivity, effective porosity, and compressibility.

d. Determine the effect of production operations, including fluid injection, on the flow characteristics of fractures.

Activity 4. Investigate the flow characteristics of fractured reservoirs using stochastic simulations of discrete fracture networks

a. Investigate the sweep efficiency of fluids injected into the fracture network.

b. Determine the effective volume of matrix blocks contacted by injected fluids as a function of well spacing and fracture network statistics.

c. Use the results of flow simulations in discrete fracture networks to develop methods for inverting the results of tracer tests to define the connectivity of fracture systems.

Activity 5. Investigate the characteristics of fracture surfaces and their influence on fluid transport in fractures and between matrix blocks and the fracture system

a. Determine the effect of the fracture surface geometry on the conductance of individual fractures and its dependence on normal stress.

b. Determine the influence of the wettability of the fracture surface on water imbibition from fractures into the matrix.

Activity 6. Define fluid flow characteristics within a fracture

a. Devise mathematical models to define fluid flow in a fracture with varying degrees of roughness and aperture size for single and multiple phase flow.

(Summary of Research Areas and Activities)

RESEARCH: AREAS → ACTIVITIES → EXAMPLE PROJECT	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
A. Recognition and Quantification of Reservoir Heterogeneity									
1. Studies of heterogeneity in outcrop of reservoir equivalents	1		X						
a. Selection of outcrop reservoir equivalents						X			
b. Establish systematic sampling procedures for outcrop data						X			
c. Detailed mapping, various outcrops						X			
d. Statistical analyses of data						X			
2. Studies of heterogeneity in modern sediments	2		X						
a. Compilation of sediment patterns						X			
b. Detailed mapping of sediment patterns							X		
c. Statistical analyses of data						X			
3. Develop rapid subsurface and laboratory methods to identify heterogeneity types	1		X						
a. Develop criteria for recognizing geological flow units in cores						X			
b. Computer applications for describing pore geometries and geologic facies							X		

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
c. Calibration of rock facies and fabrics with wireline log response						X			
d. Calibration of geophysical interpretation with geologic description							X		
4. Determine the impact of geologic heterogeneity on reservoir performance	1			X					
a. Compare field production history with geologic descriptions							X		
b. Integrate geologic heterogeneity into computer simulation of production history						X			
5. Develop methods of integrating diagenetic effects into reservoir models	2		X						
a. Effect of dissolution at all scales from karsting to fabric selective dissolution							X		
b. Origin and distribution of evaporite minerals and carbonate cements							X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
6. Determine geologic controls on residual oil	3	X							
a. Measure pore geometries and residual oil for various rock types							X		
7. Develop catalog of outcrop and subsurface studies of reservoir heterogeneity styles and production response	2	X							
8. Improve methods of using production data to locate remaining hydrocarbons	1		X						
B. Research on Interwell Measurements									
1. Well/well seismology	1		X						
a. Evaluate crosswell techniques						X			
b. Develop tomographic and reflection imaging techniques						X			
c. Enhance use of elastic waves for fluid detection							X		
d. Analyze multiple wells for 3-D imaging							X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH (AREAS / ACTIVITIES / EXAMPLE PROJECT)	Priority*	EST. ANNUAL $: < $1 MM	EST. ANNUAL $: $1MM - $5MM	EST. ANNUAL $: $5MM - $10MM	EST. ANNUAL $: > $10 MM	TIMING: < 2 Yrs	TIMING: 2 - 5 Yrs	TIMING: 5 - 10 Yrs	TIMING: > 10 Yrs
2. Well/surface seismology	2		X						
a. Demonstrate improvement in reservoir resolution						X			
b. Use of 3-component offset VSP							X		
c. VSP while drilling							X		
3. 3-D seismology	1		X						
a. Evaluation of surface seismic for reservoir description							X		
b. Inversion for porosity and fluid content							X		
4. Tracers and pressure analysis	3	X							
a. Well-to-well tracer tests						X			
b. Single-point tracer tests						X			
c. Pressure transient tests						X			
5. Horizontal wells	3		X						
a. Horizontal coring						X			
b. Transient well tests						X			
c. VSP						X			
d. Crosswell seismic						X			

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
C. Research on Borehole Measurements									
1. Rock and fluid properties derived from logs	1		X						
a. Permeability logs							X		
b. Deeper penetration								X	
c. Cased hole logging						X			
d. In-situ measurement of capillarity, wettability, etc.								X	
e. Measurement of elastic properties with seismic logs						X			
2. Predictive geochemistry	2	X							
a. Rock/fluid interactions						X			
b. Fingerprinting oils						X			
c. Water chemistry						X			
3. Rock and fluid properties derived from core	3	X							
a. Distribution and type of clays						X			
b. Stress/strain quantification and prediction							X		

*1,2, or 3

RESEARCH: AREAS → ACTIVITIES → EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
D. Integration of Numerical and Interpretive Information									
1. Develop methods for estimating rock and fluid properties from geologic, engineering, and geophysical data	2		X						
a. Integrated field studies identifying relations between rock and fluids						X			
b. Adapt and perfect geostatistical methods for quantification of uncertainty						X			
c. Develop methods of relating seismic measurements to reservoir properties							X		
2. Develop methods of inferring and quantifying continuity and anisotropy of flow properties and their extremes	2		X						
a. Statistical distributions of geometric relations of flow units							X		
b. Use statistics to develop algorithms for spatial images							X		
c. Statistics to model spatial connectivity of extreme permeabilities							X		
d. Determine the level of detail needed in quantification of reservoir heterogeneity							X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
3. Develop interactive 3-D computer graphics to display reservoir model	3		X						
a. 3-D, user-friendly software							X		
b. Software for editing model							X		
4. Develop methods of quantifying, processing, and combining information from different sources	1		X						
a. Develop methods for quantifying semiquantitative data						X			
b. Develop algorithms for fast 3-D multiple attribute conditional simulation						X			
c. Quantify uncertainty about reservoir attributes and resulting uncertainty in reservoir performance						X			
5. Develop methodology for definition of simulation block architecture that reflects geologic flow units (scaling up)	3	X							
a. Techniques for assigning absolute and relative permeabilities to simulator blocks						X			
b. Interactive software to complete (a) above on workstations							X		

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
E. Fractured Reservoirs									
1. Develop geophysical methods for characterizing fractures	1		X						
a. Measurement of shear-wave azimuthal anisotropy							X		
b. Use of shear-wave attenuation							X		
c. Effect of fluids on seismic response from individual and multiple fractures							X		
d. Electrical mapping of fracture systems							X		
2. Determine the statistical characteristics of fracture networks	1		X						
a. Outcrop mapping of fractures						X			
b. Develop methods for determining fracture apertures downhole							X		
c. Horizontal wells							X		
d. Frequency distribution of intact block size							X		

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
3. Determine the effects of stress and strain on characteristics of fracture networks	3	X							
a. Predict fracture orientation from regional stress field						X			
b. Relationship of structure and lithology on fracture characteristics						X			
c. Effect of stress on flow characteristics						X			
d. Effect of producing operations on flow characteristics						X			
4. Investigate the flow characteristics of fractured reservoirs using stochastic simulations of discrete fracture networks	2	X							
a. Sweep efficiency of injected fluids						X			
b. Volume of matrix blocks contacted by injection fluids						X			
c. Integrate fracture descriptions and tracer tests						X			

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
5. Investigate the characteristics of fracture surfaces and their influence on fluid flow	3	X							
a. Fracture surface/conductance relationships						X			
b. Relationship between fracture wettability and imbibition						X			
6. Define fluid flow characteristics within the fracture	2	X							
a. Mathematical models for single and multiple phase flow						X			

*1,2, or 3

RESERVOIR PERFORMANCE PREDICTION AND EVALUATION

Geoscience Institute
Technical Subcommittee Report

for

U.S. Department of Energy
Office of Fossil Energy

Prepared by

Larry W. Lake, University of Texas*
Hossein Kazemi, Marathon Oil Company*
Michael A. Adewumi, Pennsylvania State University
Albert Carnes, Core Laboratories, Inc.
Anil Dandona, Mobil Exploration and Production Service
Richard E. Ewing, University of Wyoming
Michael J. King, BP America, Inc.
Douglas A. Lawson, Stanford University
Franklin M. Orr, Jr., Stanford University

*Subcommittee Co-chairmen

RESERVOIR PERFORMANCE PREDICTION AND EVALUATION

PROBLEM DEFINITION

Exploring for oil constitutes a classic definition of a risky venture. Even with the oil found, producing the oil entails a measure of risk which, unfortunately, increases with the complexity of the recovery method being employed Usually this means an enhanced oil recovery (EOR) process. Unlike exploration, however, the potential for large cash returns in production, even with significant improvements, is small, a situation which makes accurate risk assessment even more important.

The way to minimize (or at least evaluate) the risk inherent in a given operation is to accurately predict the amount of petroleum that will be recovered and the length of time this recovery will require. Such a prediction has several beneficial effects; it allows

1. Matching a given (EOR) process to the appropriate reservoir,

2. Evaluation of design and project alternatives, and

3. Monitoring project performance and evaluating mid-course corrections.

The confidence derived from accurate predictions should allow operators to increase oil recovery by instituting more projects and better management.

BACKGROUND AND STATUS

Predicting petroleum recovery has matured from straightforward decline curve analysis, volumetrics, and elementary material balances to highly sophisticated numerical simulation. The former techniques are still being used on small projects where economics prohibit the use of numerical simulation. The dissemination of these techniques among independent operators and consultants is addressed in the technology transfer section of this report. It is the larger and more complex projects which are now being simulated numerically. Inasmuch as this trend towards complex simulations is almost certain to continue, the bulk of the reservoir prediction and evaluation section of this report will deal with numerical simulation.

The growth in the size, sophistication of and confidence in numerical simulators in a little over 20 years has been tremendous. This growth has been fueled by two trends. There exists an evolutionary trend wherein numerical methods and physical models of increasing sophistication have been introduced and put into practice. A good example here is the increasing use of high-order spatial approximations and implicitness. The second trend has been the revolutionary trend in the size and speed of computer hardware within the last 10 years. The increase in size and speed has exposed deficiencies in many of the numerical procedures and especially in the quality and quantity of the data which the simulators process to generate answers.

The advances just described have led to a high degree of confidence in black-oil simulations of geologically simple reservoirs. However, the future is expected to place increasing emphasis on EOR and complicated geology. Existing simulation technology is unsatisfactory for these applications because geological data are incomplete, physical flow processes insufficiently understood, and numerical methods inadequate. EOR simulation is more sensitive than primary recovery or waterflooding simulation to the effects of heterogeneity, viscous fingering and dispersion.

RESEARCH APPROACH

Much could be done to improve the ability to predict reservoir performance. The recommended research falls into the three areas listed below:

1. Improving quality of data input to numerical simulators. The actual generation of data for and interpretation of reservoirs is covered in the Reservoir Characterization portion of this report. This section is concerned with how those observations are translated into sets of numbers which are accurate, faithful to the geology of the reservoir, and useful in simulation. Much of the research deals with geostatistics, a relatively new area which is providing new insights into reservoir description. Geostatistics and its associated discipline, conditional simulation, also provide a quantitative means of risk assessment. Sensitivity studies will show how much data is needed, and how accurate data must be in order to obtain results of practical value.

2. Adjusting mathematical models and numerical input data to be scale-consistent. Oil reservoirs are immense, three-dimensional flow fields whose inner workings are susceptible to observation at only a few points. The points are the well-bores which provide the rock and fluid samples as well as petrophysical data through wireline logging devices. The numerical models of such reservoirs are very large, taxing the limits of even the next few computer generations. (Only numerical simulation of atmospheric phenomena requires larger models.) The size of the flow field cells are of the order of tens to hundreds of feet which the laboratory samples, upon which the input is based, are generally a few inches in size. The mathematical model must be constructed to represent the physical processes at this length scale, including averaging of flows at smaller scales, and the numerical input must scale-adjusted to reflect this size. Even a perfect reservoir characterization could not be used in a predictive mode without this scaling.

3. Developing numerical methods for advanced computing. Entirely complementary with the above is the development of numerical techniques to take full advantage of large-scale computers. Three areas are important: (1) development of improved methods to take advantage of vector processors, (2) moving large-scale computation onto parallel processors, and (3) developing methods for improved numerical accuracy. More accurate methods play a central role because they enable the computer to be used as an experimental tool in the study of sensitivity to data (item 1 above), scaling (item 2), and macroscopic physics of fluid flow.

RESEARCH AREAS

Nonsimulation Predictive Methods.

Two nonsimulation techniques are described for simulator validation.

1. Development of Statistical Correlations for Oil Recovery

Correlations can be developed using the recoveries from existing fields as a function of reservoir rock, fluid properties, well spacing, and geologic observations in the outcrop. In many cases, these relationships will come from dimensionless groups derived from scaled simulator studies.

2. Physical Processes and Models

Confidence in numerical models comes from their degree of success in predicting physical observations. Petroleum recovery models have traditionally been hindered in this regard because field tests are too complicated to interpret unambiguously and direct observation is generally not possible in laboratory experiments because flow in permeable media cannot be easily and correctly visualized. Recent developments in computerized tomography (using either X-ray or magnetic sources) have shown promise in providing this visualization.

Accurate Numerical Simulator Input

It is axiomatic that the accuracy of a simulation result can be no better than the information upon which the calculation is made. Much of the input to a reservoir simulator is geologically or petrophysically-based and much of this information can be only crudely used in simulation input. The idea behind this research area is to improve the quality of simulation input.

1. Deterministic input

Simulator input has historically been deterministic or static. Deterministic information is always preferable to statistical information. However, methods must be pursued for representing deterministic information which exhibits large uncertainties. Methods must be improved for translating geological and geophysical information into simulation parameters (and visa versa so that the simulator can be constrained.

2. Stochastic parameter assignments

Stochastic parameter assignments generate flow fields according to various moments and percentiles of statistical distributions. The flow field must be conditioned or made to match deterministic information where these are available. The statistics are derived from existing data, additional sampling, or from new geological observations (see Reservoir Characterization). Priorities are generally high because these techniques impact directly on risk assessment. Stochastic assignments can also give insight to the sensitivity of the inter-relations of the various variables.

Studies on Basic Fluid Flow Physics

Effective process design rests on a fundamental understanding of the basics of fluid flow physics in permeable media. Much has been done in this area, but prior studies have been limited to rather unrealistic media and experiments. Improved numerical techniques (see below) coupled with highly efficient codes should allow complex studies of fluid flow which, in turn, will improve understanding and the ability to scale-up information.

1. Basic fluid flow studies in complex media.

Several competing effects exist even within relatively simple flow fields. The predominance of one of these effects over another determines how the process scales from one length to another (as in laboratory to field scale). The history of such scaling is to determine the important effects on a small scale and then imagine that these carry over to a larger scale through matching various dimensionless groups. The same applies to viscous fingering, the understanding of which is critical to risk assessment in EOR. Unfortunately, the basic determinant in fluid distribution--heterogeneity--cannot be treated in such a fashion (laboratory heterogeneity cannot be made equivalent to field heterogeneity). Thus, ideally, it is important to thoroughly understand all of the flow regimes which can occur and to be able to anticipate the scale at which they are important. Numerical simulation is a basic tool for such studies.

2. Rock-fluid properties

The complex geometrical considerations and flow idealizations discussed above are derived from our understanding of small-scale (local) physics. Despite considerable success in this area, there are still fundamental questions unanswered.

3. Near-well and wellbore effects

Many times it is the properties of the wells and of the near well region of the reservoir which determine success. Such areas are hard to model because of steep gradients and rapidly changing conditions. In addition, well-bore hydraulics, especially in multiphase flow, play a significant role in reservoir performance prediction; hence, accurate coupling of reservoir simulator with well-bore hydraulics is of paramount importance. There are three sample projects dealing with well modeling and coupling including the modeling horizontal wells.

<u>Numerical Issues</u>

Much of the success of the prior work depends on the ability to make accurate large-scale calculations using small-scale laboratory measurements, and to effectively use large-scale simulators. Some specific numerical issues concerning accuracy and use are given here.

1. Local grid refinement

Much additional accuracy can be gained by refining numerical grids in areas where properties change abruptly. There are two basic types of such refinement--adaptive, where the grids adjust with time, and non-adaptive, where local refinement is static.

2. More accurate and cost-effective discretization methods

Physical dispersion is a crucial process in permeable media flow, particularly as it relates to scale-up issues, heterogeneity, and viscous fingering. Unfortunately, the upstream-weighted finite-difference numerical approximations commonly used in reservoir simulation generate a spurious type of error known as numerical dispersion. Research on better methods to overcome this limitation is rather sophisticated, but to date relatively few of the promising techniques have been carried through to common practice.

3. High order convergence

Large-scale computation requires that approximated flow equations arrive at converged solutions rapidly. In fact, slow convergence techniques can nullify much of the advantage in using vectorized codes. Because the equations that simulate a time step are usually nonlinear, this issue relates to two steps; the first is the outer interation that linearizes the nonlinear equations, and the second is the inner iteration that solves the linearized equations for each outer iteration. More efficient techniques should be developed in the context of various forms of implicitness.

4. Domain decomposition/parallel processing

Another method of increasing computation speed is to make calculations simultaneously. This is the basic idea behind vectorization and parallel processing; however, even greater speed can be attained by solving portions of the same problem simultaneously with a technique known as domain decomposition.

5. Stability of hysteresis representations

Hysteresis here refers to the dependency of flow properties on the direction in which saturations are changing. Such effects have been recognized for a long time, but are generally ignored in modeling because they introduce complexity and even convergence difficulties. Recent information (carbon dioxide injectivity and displacement efficiency in the water-alternating CO_2 process, for example) suggests that modeling hysteresis is important and should be the subject of research.

<u>Scale-up: Laboratory to Pattern Element (pilot) to Sector to Field.</u>

Scaling up well-understood processes is an important step in improving reservoir performance prediction. Such a process involves a thorough understanding of the physics of the flow in the medium, fluid and rock properties and their interactions, and a knowledge of the role of heterogeneity. Scaling up also is a procedure for adjusting simulator physical property relations to account for the largeness of grid-block size.

1. Averaging procedures

Averaging procedures seek to incorporate the small-scale flow properties mentioned above into "effective" or scale-adjusted properties. If done correctly, such procedures will give appropriate weight to all influencing factors.

2. Numerical methods to account for scaling.

Other types of averaging may be necessary to produce the correct fluid distribution for all scales of measurement. These scale-ups, such as that for viscous fingering, are among the most important for EOR and, unfortunately, the most poorly understood. Different processes are important at different length scales, and it is important to understand how they relate to each other.

3. Reformulation of flow equations

Some evidence, both experimental and theoretical, suggests that scale-averaged equations will take on a form somewhat different from the small-scale representations. This highly interesting fact deserves research activity.

Flow Representation in Nonuniform, Heterogeneous Fields

Nonuniform, heterogeneous flow fields are those for which at least one property cannot be represented by a single "white" probability function. In petroleum recovery the most important of such fields result from discontinuous facies in and tectonic failure of the reservoir rock. These effects are manifest as fractured reservoirs and reservoirs intermingled with discontinuous shales.

1. Fractures, faults, and pressure solution (permeability) channels

These geologic phenomena are either high-conductivity or nearly impervious paths which are generally detrimental to efficient EOR schemes. Their prevalence makes them a major source of trapped or bypassed oil, particular in EOR processes. Improved numerical representation could come from a thorough understanding of how fluids flowing through and about them interact with the bulk of the matrix material.

2. Shales and facies boundaries

Shales, shale lenses and erosional contacts within the reservoir, on the other hand, are simply low-conductivity regions which can act as horizontal and vertical barriers to a displacing agent. Their discontinuous and apparently unpredictable distribution makes it necessary to represent them statistically.

Numerical Simulator Validation

Strong emphasis is placed on validating or verifying the results of numerical simulators. In the final analysis, this procedure is impossible on any significant scale; however, its importance suggests research in the following activities.

1. Use of physical models (CT scanning)

See discussion above under nonsimulation techniques.

2. Analytic end members

A basic way to validate a numerical simulator, at least in a limiting sense, is to compare it to analytical solutions of simplified flow problems. Such comparisons are routinely done; however, the number of analytical solutions is too small to imply thorough validation.

3. Comparative evaluation

In the last few years there has been substantial effort in quality control of numerical simulators through relative evaluation of several simulators run on an identical problem. This procedure should be standardized and expanded to include physically more realistic simulation models.

4. Retrodiction

Retrodiction is the "predicting" of a past occurrence. This type of post mortem analysis has rarely been reported in the petroleum literature, yet it provides an excellent means of simulator validation.

5. Convergence analysis

A direct means of simulator validation is to compare the rates of convergence to theoretical standards. This is a check on the numerical procedure of the simulators but both theoretical and numerical research are required to bring it to fruition.

Reservoir Performance Prediction and Evaluation

(Summary of Research Areas and Activities)

RESEARCH: AREAS → ACTIVITIES → EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
A. Nonsimulation Methods									
1. Statistical correlations	1	X				X			
a. Identify reasons for bypassing - heterogeneities	1	X				X			
b. Recovery from existing fields as a function of reservoir rock and fluid properties and well spacing	1	X					X		
2. Physical processes and models (CT scanning—both NMR and X-ray)	1	X					X		
a. Dispersion/fingering studies	1	X					X		
b. Flow in layered media	1	X					X		
c. Relative permeability and capillary pressure control	1	X					X		
B. Accurate Numerical Simulator Input									
1. Deterministic	1	X							
a. History match procedures	1					X			
b. Consistent physical relations	1						X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
2. Stochastic–geostatistics	1	X							
a. Best way to generate a random field and how to condition (as in satisfy a well test, tracer survey, geology)	1						X		
b. How to minimize number of realizations	1						X		
c. Evaluation of uncertainty	1						X		
C. Fluid Flow Physics									
1. Basic fluid flow studies	1	X							
a. Crossflow	1					X			
b. Gravity and mixing	1						X		
c. Viscous fingering and dispersion	1						X		
2. Rock–fluid properties	1	X							
a. Composition dependence	1					X			
b. Wettability	1						X		
c. Adsorption/desorption (tight gas)	3						X		
d. Non–equilibrium	2						X		
3. Near–well and wellbore effects	1	X							
a. Multiphase flow wellbore model	1						X		
b. Well block heterogeneity	1						X		
c. Horizontal well representation	1						X		

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
D. Numerical Issues									
1. Local grid refinement	1	X							
a. Wells and pinchouts (non-adaptive)	1					X			
b. Fronts (adaptive)	1						X		
2. More accurate discretization methods	1	X							
a. Finite elements	2						X		
b. Mixed FE/FD methods	2						X		
c. High-order approximations	1						X		
d. Front-tracking methods	2						X		
e. Method of characteristics	1						X		
3. High-order convergence	2	X							
a. Linearization	2					X			
b. Linear equation solvers	2					X			
c. Increased implicitness	2						X		
4. Domain decomposition/parallel processing	2	X					X		
5. Stability of hysteresis representations	1	X				X			

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS → ACTIVITIES → EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
E. Scale-Up: Lab-Pattern Element (Pilot)-Sector-Field. Requires Local Physics, Geologic Description, Process									
1. Averaging procedures	1	X							
a. Permeability	1					X			
b. Capillary pressure	1						X		
c. Relative permeability	1						X		
d. Dispersivity	1					X			
e. Fracture networks	1					X			
2. Numerical methods to account for scaling	1								
a. Macroscopic method for fingering	1	X					X		
b. Macroscopic models for small-scale heterogeneities	1	X					X		
c. Averaged near-well models	1	X					X		
3. Possible reformulation of equations	3	X				X			
F. Flow Representation in Nonuniform, Heterogeneous Fields									
1. Fractures, faults, and solution channels	1	X							
a. How to represent in simulator	1	X					X		
b. Mass and momentum transfer characteristics	1	X					X		
c. Geometry	1	X				X			

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH (AREAS / ACTIVITIES / EXAMPLE PROJECT)	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
2. Shales and depositional facies	1	X							
a. How to represent in simulator	1	X					X		
b. Geometry	1	X					X		
G. Numerical Simulator Validation									
1. Use of physical models (CT scanning)	1	X					X		
2. Analytic end-members	3	X					X		
3. Comparative evaluation	2	X							
4. Retrodiction - "predicting" a past occurrence	1	X							
5. Convergence analysis	1	X							
a. Theoretical studies							X		
b. Numerical studies							X		

*1,2, or 3

ADVANCED EXTRACTION TECHNOLOGY

Geoscience Institute
Technical Subcommittee Report

for

U.S. Department of Energy
Office of Fossil Energy

Prepared by

Don W. Green, University of Kansas*
Robert N. Healy, Exxon Production Research Company*
John L. Cayias, Sun Exploration & Production Company
Lyman L. Handy, University of Southern California
Jeffrey Hanor, Louisiana State University
Michael M. Prats, Shell Development Company
Fred I. Stalkup, ARCO Exploration Technology-PRC
William C. Tosch, Pennsylvania State University
Edward Witterholt, Standard Oil Production Company

*Subcommittee Co-chairmen

ADVANCED EXTRACTION TECHNOLOGY

PROBLEM DEFINITION

For light oil reservoirs, it is generally accepted that, on average, the application of primary recovery processes plus secondary recovery processes such as waterflooding yields only about one third of the oil originally in place in a reservoir. The remaining oil in known fields has been determined to exist in two basic forms. A large fraction exists as immobile oil in regions of the reservoir previously swept by water or other immiscible displacement fluids such as gas. This oil is typically in the form of discontinuous droplets or ganglia which are trapped by large capillary forces. The other fraction of the oil, the mobile oil fraction, is in regions of the reservoir that were never contacted by the displacing fluid. This oil was bypassed because of adverse effects of well pattern geometry, unfavorable mobility ratios and reservoir heterogeneities.

For heavy oil reservoirs, oil recovery from conventional recovery processes is limited because of the low mobility of the viscous oil.

Under the right conditions, advanced extraction technology can be employed to recover a significant part of the mobile and immobile oil that remains in existing light oil reservoirs. Advanced extraction technology can also be used to produce heavy oil. There are a number of different enhanced oil recovery (EOR) processes that are known and these vary both in cost of implementation and in technical complexity. A problem is that no single method is applicable to all reservoirs because of the variability of both the nature of the oil and the reservoir types. The cost of applying the processes tends to restrict their commercial application, especially in times of low oil prices. For most processes there is incomplete understanding of the actual mechanisms of recovery that are operative in a reservoir and this leads to uncertainty in design and implementation.

The reasons for conducting research on advanced extraction technology are several. There is incentive to increase understanding of known processes and to use this understanding to improve process design and process efficiency. There is an opportunity to reduce the costs of implementation of processes through improved design, improved process efficiency and through development of better and cheaper chemicals which are used in the processes. There are opportunities to develop methods of increasing volumetric sweep efficiency through improvement of mobility control or application of horizontal wells, for example. There is potential to improve our understanding of basic fluid and rock properties and interactions in flow processes in porous media. We could improve our understanding of how to scale laboratory studies to the field, a difficult task concerning oil reservoirs. And we should continue to search for additional, yet undefined, oil recovery processes.

Several national studies have estimated the potential results of widespread implementation of advanced extraction technologies to existing fields. The projections are that several billion barrels of oil could be recovered by utilization of EOR processes. The potential oil recovery from EOR processes, of course, is strongly dependent on oil price.

BACKGROUND AND STATUS

The extraction technologies considered here have, for the most part, existed for some time although there is a wide variation in the relative degree of application and understanding. Waterflooding has been applied for many years and is relatively well understood. At the other extreme are rather novel processes such as the use of microbial organisms. For this latter process we are on the very early part of the learning curve and considerable research remains to be done.

The most significant EOR processes include thermal methods, the use of chemicals such as polymers and surfactants, and miscible processes such as carbon dioxide flooding. These processes too are at various states of development. Steam flooding is probably best understood, followed by polymer-augmented waterflooding and miscible displacement. Surfactant processes are probably the most technologically complex and expensive, and the least well understood.

The potential future oil recovery that might result from implementation of the most important EOR processes has been considered in a number of national studies. One of the most recent was conducted under the auspices of the National Petroleum Council (NPC, 1984). A conclusion was that a significant amount of oil could be recovered by utilizing the different processes on a wide scale, economics permitting. It was concluded that much is known about a number of the processes, but that there are opportunities for continued technological advances.

POTENTIAL RESEARCH OPPORTUNITIES

To summarize potential research, six areas have been identified. There are opportunities for basic research on rock/fluid properties and interactions between rock and fluids. Such research should lead to improved general understanding of oil recovery. In essentially all recovery processes, failure to contact the total reservoir volume is a significant problem so a second research focus is on improved volumetric sweep efficiency. A third research area is that of predicting field performance based on experimental results obtained in a laboratory, i.e., scaling of laboratory data is a long-standing problem that should be addressed to make laboratory studies more useful for field applications.

Most of the EOR processes could benefit from an improvement of the basic understanding of the physical/chemical mechanisms which are important. This fourth research area on fundamental mechanisms should lead to improved design and implementation of EOR processes. An associated fifth research area, process enhancement, deals with studies to improve or extend the applicability of processes. Finally, research in the area of reservoir evaluation or screening for EOR processes, and monitoring of EOR process performance may be beneficial.

RESEARCH AREAS

Potential research has been categorized by areas and activities in Table I. Priorities (1 - higher to 3 - lower) have been assigned to the activities. Table I also gives example projects corresponding to research activities. It is emphasized that the example projects listed are illustrative of possible work within the research activities and in no way imply that the projects should necessarily be funded. Funding of any project should be done on the basis of the merit of a submitted proposal.

Research activities were prioritized using four general criteria:

i) Multidisciplinary nature of the activity.
ii) Potential of the activity to contribute to increased oil recovery.
iii) Probability of conducting successful research within the activity.
iv) Compatibility with research capabilities of university programs.

Although no specific assumptions were made about oil price, a general premise used to prioritize activities was that prices would gradually increase to about \$25-\$30 per barrel by the end of the century. Priorities would have been different if the assumption had been made that there would be no increase in price over the next 10-15 years. It is emphasized that, regardless of assumptions about oil price, proposed research activities would be beneficial and could lead to increased oil recovery.

Most of the potential research identified by the subcommittee relates to problems that have been actively studied by both industry and academia for years. However, they are very difficult problems and there remains additional research that would be appropriate for consortium members to undertake.

A consideration in setting priorities was the way in which research results might be used to benefit the petroleum industry. University research programs are, in general, suited to conducting research of a basic and fundamental nature. Such research is extremely useful in that it complements work done in the research laboratories of the major petroleum companies. Thus, a high priority was given to fundamental research of rock/fluid properties and interactions. Our list of research areas also contains activities that are more applied in nature (e.g., Reservoir Evaluation and Monitoring for EOR) that should be of use to smaller oil companies.

The subcommittee felt that it was not appropriate to make estimates of funding required to pursue the identified research activities. The level of funding must be based on the quality and nature of research proposals that are developed by consortium members. Only proposals that are of high quality should be funded. For those proposals that are funded, the level of funding should be governed by the requirements of the project and not by a dollar amount estimated a priori by the subcommittee.

Finally, for the research activities and example projects, it was assumed that the conditions (temperatures, pressures, stresses, concentrations, environment, etc.) at which the research would be conducted would be suitable for the process and reservoir conditions under consideration. Generally, the conditions were not specified in order to avoid unnecessary repetition.

The following is a discussion of items in Table I.

<u>Rock/Fluid Properties and Interactions</u>

The goal of this research would be to understand how rock pore morphology and mineralogy, fluid compositions, and physical and chemical properties could be used to correlate and predict basic physical properties, including permeability, relative permeabilities, contact angles, capillary pressures, adsorption, thin-film formation, dispersivity, etc.

The improved level of understanding arising from this basic research might lead to innovative approaches to control microscopic physical transport and displacement mechanisms, and thus to increased hydrocarbon production.

Activities

1. Rock/Fluid Interactions

   The goal would be to understand and model rock/fluid physical, chemical and thermal interactions. The physical and chemical mechanisms of adsorption would be related to the molecular structure of fluid components and atomic and crystallographic structure of reservoir pore surfaces. The molecular, ionic, and thermodynamic factors controlling contact angles and thin film formation would be explored. Modern surface science tools (e.g., fluorescent microscopy, ellipsiometry, electrochemistry, surface force (disjoint force) measurements, NMR, ESR, etc.) would be considered in the study of fluid-solid interactions.

   Example Projects

   1. Methods for characterizing and altering wettability
   2. Mineralogy and pore-structure effects on fluid distribution
   3. Advancement of CAT-scan and NMR imaging methods
   4. New approaches to the study of rock/fluid interactions
   5. Laboratory investigation of capillary pressures and relative permeabilities for enhanced recovery processes
   6. Development of new or improved methods for predicting relative permeabilities for enhanced recovery processes
   7. Fundamental investigation of thin-film drainage and flow recovery mechanism
   8. Predictive models of mineral-fluid reactions

9. Characterization and permeability implications for fines movement in porous media

2. Fluid Properties

The goal would be to provide fluid properties (e.g., microstructure, transport, rheology, phase behavior, interfacial tensions, etc.) for both the Rock/Fluid Interaction Activity (microscopic level) and for the proper application (macroscopic) of any advanced extraction processes.

Example projects

1. Predictive models for density, viscosity and phase behavior of reservoir/EOR fluids
2. Laboratory measurement of reservoir-fluid physical properties at high temperatures and pressures

3. Rock Properties

One goal would be to develop experimental methods (e.g., electron microscopy image analysis and x-ray, CAT-scanning or NMR imaging studies of pore morphology, x-ray-scattering, x-ray dispersive analysis of mineralogy of pore contents and surfaces) and physical and mathematical models (e.g., methods and computer software for translating data into needed pore statistics) for the characterization of pore structure and composition in support of the Rock/Fluid Interaction Activity. A second goal would be to provide non-routine transport and mechanical properties of reservoir rocks.

Example Projects

1. Porosity-permeability correlations and their dependence on reservoir conditions
2. Laboratory study of compaction, subsidence, rebound and creep effects on physical properties such as porosity and permeability (especially for simulating fractured reservoirs and permafrost environments)

<u>Increased Volumetric Sweep Efficiency</u>

Oil recovery in any displacement process (waterflooding or EOR methods) depends upon and is improved by increasing two parameters: unit displacement efficiency and volumetric sweep efficiency. The latter is a measure of the total reservoir volume that is contacted by the injected fluid. For simplicity, volumetric sweep efficiency is divided into two components: areal and vertical sweep. Areal sweep is primarily a function of flood pattern geometry, areal heterogeneities, and the mobility ratio of the displacing fluid vs. the displaced fluid. Vertical sweep is also a function of mobility ratio and the degree of heterogeneity in rock layers or strata. Therefore, to improve recovery of oil from reservoirs, we must address mobility ratio and improve or attempt to nullify the adverse effects of permeability variability both in the near-well regime and in-depth in the reservoir.

Activities

1. Mobility Control

Carbon dioxide, hydrocarbon gases and different inert gases are widely used as EOR chemicals, particularly as miscible displacement fluids. Their effectiveness is diminished due to the low viscosity of the gases (high mobility) which leads to a relatively low volumetric sweep efficiency when the gases are used in displacement processes. There is potential to develop better methods of mobility control which could improve process performance.

Example Projects

1. Viscosifiers for CO_2 systems (polymers, foams, etc.)
2. Development of CO_2-external foams
3. Development of new viscosifying agents for high-temperature and high-salinity applications
4. Characterization of emulsion flow in porous media

2. Near-Well (Profile Control) and In-Depth Permeability Modification

Variable permeability profiles, whether near-well or in-depth, can sometimes be improved by proper polymer/gel systems or precipitation techniques that tend to reduce (<u>not</u> eliminate) permeability to fluid flow. Also, the rigidity or permanency of these gels and how they are placed within the reservoir are of key importance.

Example Projects

1. Development of polymer-gel systems with controlled gelation time to allow flexibility in selective placement
2. Development of methods involving chemical reaction and precipitation for plugging selected regions of a reservoir

3. Operational Strategies

Better operational strategies (well placement, completion strategies, horizontal wells, etc.) could lead to increased recovery of immobile and mobile unswept oil. Better reservoir description and simulation techniques could lead to better operational strategies. Through proper reservoir management using geologic and engineering data, a considerable amount of additional oil might be recoverable.

Example Projects

1. Simulation of gel placement and its effect on process performance
2. Completion strategies
3. Optimization of sweep efficiency through location of wells and/or use of horizontal wells

<u>Prediction of Field Performance from Laboratory Studies</u>

Reliable prediction of field performance of EOR processes would aid in managing current field projects and in evaluating and designing planned field projects. It is often not possible to conduct laboratory experiments that are completely scaled for field conditions; consequently reservoir simulators are usually employed to predict field performance. Crucial input data for these simulators are obtained from laboratory measurements.

There are two problems associated with use of laboratory data in reservoir simulators. The first concerns interpretation of laboratory experiments for variables of interest. For example, results of laboratory coreflooding experiments can be obscured by such things as end effects, gravity override, viscous fingering, etc. The second problem is related to the assignment of single values of variables to a simulator grid block. These grid blocks are often quite large for field scale studies and a single value for a variable is not appropriate. For example, a single value of water saturation is not realistic for a large grid block in a field-scale simulation.

Activities

1. Laboratory Studies

   Interpretation of coreflooding experiments for EOR processes is frequently complicated by factors such as viscous fingering, gravity override, end effects, etc. Better methods to interpret corefloods would be useful. The conducting of well-characterized physical model experiments to obtain performance data which could be used to verify mathematical simulators would be beneficial.

   Example Projects

   1. Dispersive mixing
   2. Viscous fingering

2. Process Simulation

   Current EOR process simulators are often restricted to modeling performance of only a small portion of a field because of practical limitations on the number of grid blocks that can be used. Detailed modeling is commonly done on only a small portion of a field or an element of a repeated pattern. Improved methods would enable EOR simulators to be more effectively used to make predictions on a larger scale.

Example Projects

1. Grid-block size effects
2. Numerical dispersion

Improved Understanding of Process Mechanisms

A better fundamental understanding of the mechanisms for EOR processes should allow design of more cost-effective and more widely applicable processes. This requires an integrated study of the physics, chemistry and flow behavior of complex rock/fluid systems. Studies which would lead to improved representations of the important mechanisms in mathematical simulators would be especially significant.

Activities

1. Miscible/Immiscible Gas

Correlation of process performance in laboratory corefloods with rock/fluid physical properties and interactions could lead to better screening and design procedures for flooding processes.

Example Projects

1. Effect of mass transfer, e.g., dispersive mixing, on process performance
2. Mechanisms of oil trapping/bypassing in WAG miscible floods and role of mass transfer in recovery
3. Effect on displacement behavior of three-phase region in CO_2-hydrocarbon displacement process
4. Improved mechanistic description of viscous fingering
5. Role of combined viscous and gravity instabilities in process performance

2. Foam/Emulsion

Foams and emulsions have potential to improve sweep efficiency and oil recovery for EOR processes. A better, pore-level understanding of the mechanisms of mobility control for foams and emulsions would be beneficial. Correlations of process performance in laboratory corefloods with fundamental measurements of rock/fluid properties and interactions would also be useful.

Example Projects

1. Definition of foam transport and oil-displacement mechanisms
2. Effect of mass transfer, e.g., dispersive mixing, on process performance

3. Correlation of fluid physical properties with process performance

3. Steam

Although the technology of steam processes is mature and these processes are widely applied commercially, there are still certain fundamental areas that could benefit from additional research. For example, the factors controlling steam mobility and final oil saturation after steam flooding need to be better established.

Example Projects

1. Determination of factors controlling steam mobility
2. Determination of factors controlling final oil saturation

4. In Situ Combustion

Most laboratory and theoretical studies of in situ combustion have involved linear displacement. However, there is incentive to examine the effects of gravity override that often occur in field applications.

Example Projects

1. Effect of dispersive mixing on process performance with gravity override

5. Microbial

Mechanisms for microbial EOR processes need to be much better established before potential for these processes can be realistically assessed.

Example Projects

1. Fundamental study to elucidate mechanisms

6. Micellar/Polymer

The effects of surfactant/polymer interaction can limit oil recovery from micellar/polymer processes. Better definition of these effects should enable design of more cost-effective flooding processes.

Example Projects

1. Determination of polymer/surfactant-interaction effects on process performance

7. Polymer Augmented Waterflooding

Although the mechanisms of polymer-augmented waterflooding are well established, the relative contributions of viscosity increase and permeability reduction to mobility control are not completely understood.

Example Projects

1. Determination of relative contribution of viscosity and permeability reduction to mobility reduction

8. Alkaline

Although alkaline flooding apparently has limited potential for commercial application, there is some incentive to better define mechanisms for novel approaches such a surfactant-aided alkaline flooding

9. Miscellaneous

This activity should cover study of mechanisms for any promising new approaches to EOR not listed above.

Example Projects

1. Definition of mobility-control and oil-displacement mechanisms for liquid-crystal systems

Process Enhancement

Many processes to increase oil recovery (EOR processes) have been utilized. Enhancements of these processes could lead to increased applications or, in some cases, commercial viability of these processes. Some of the processes, such as microbial, are still in the early stages of research and will not likely result in recovery of large amounts of oil in the near term. Other processes such as steam and miscible gas flooding account for most of the enhanced oil recovery today and improvements in these processes could increase oil production in a short period of time. One of the more significant processes, the CO_2 water-alternating-gas injection process, or WAG, is complex and varied in its application. Process refinements such as WAG could benefit from work to maximize effectiveness.

Economic variables play a major role in determining what processes, if any, could reduce the rate of decline in U.S. oil production. In all of the EOR processes, the price of crude oil is a critical economic variable and dictates the degree of process enhancement necessary to make a process commercially viable.

Activities

1. Thermal

Thermal processes employ heat as a means to increase oil recovery and include in situ combustion, cyclic steam soaks and steam drives. By far, the two most widely used EOR processes are cyclic steam soaks and steam drives for increasing recovery in heavy oil reservoirs. The steam processes also account for the majority of the current EOR production in the U.S.

Example Projects

1. Examination of thermal-recovery mechanisms and potential for light-oil targets
2. Investigation of pressure effects in steam flooding shallow reservoirs
3. New approaches for effective steam flooding in thin reservoirs
4. Development of thermally stable chemicals (for foams, etc.)

2. Chemical

Chemical processes, as considered here, use chemicals such as surfactants, bases and polymers to increase oil recovery. There are two major areas into which these processes can be grouped. One area is processes which use chemicals to address recovery of residual oil. Examples of this type of process would be surfactant-polymer flooding and alkaline flooding. These processes address the large amounts of residual oil that will remain after primary and secondary recovery, but they require large capital investments. The other major area is processes which use chemicals to address improved mobility control or vertical flow profile control. Examples of this type of process would include polymer flooding and polymer cross-linked gel treatments for flow profile control. These processes require less capital investment, but only address recovery of mobile oil.

Example Projects

1. Development of high-temperature, high-salinity surfactants and polymers
2. Investigations aimed at reducing sensitivity of phase behavior and interfacial properties to variations in temperature and salinity

3. Miscible/Immiscible Gas

This process area includes the use of CO_2, nitrogen, flue gas and hydrocarbon gas as injectants to increase oil recovery. However, availability of these injectants is often limited. There is need to devise approaches that would make these injectants more broadly available. This would lead to broader application of the processes.

Example Projects

1. Improvement in gas availability, e.g., membrane separation, etc.

4. Enhanced Gas Recovery

This area includes methods to increase gas recovery from conventional and unconventional sources. Horizontal wells and improved completion techniques represent potentials to improve recoveries in conventional reservoirs.

Example Projects

1. Development of methods to recover gas from unconventional sources, e.g., Devonian shales, gas hydrates

5. Single-Well EOR

The widespread use of cyclic steam stimulation is an example of how a single-well process can increase oil production. There could be a benefit from improving and developing single-well processes such as cyclic CO_2 or cyclic chemical processes to allow a single well operator to apply advanced technology to increase oil recovery.

Example Projects

1. Laboratory and simulation study to support development of quick-response methods like cyclic CO_2
2. Processes for small reservoirs

6. Novel EOR

This area considers process enhancements to extend existing processes. The applicability of light oil recovery methods to improve recovery of heavy oil, and the use of steam in light oil reservoirs to enhance light oil recovery would be examples of such process extensions.

Example Projects

1. Development of solvent process for heavy-oil recovery

7. Stimulation

The methods used to complete and stimulate a well play a major role in enhanced oil and gas recovery processes. There is currently no generalized set of guidelines for stimulation associated with the various EOR processes.

Example Projects

1. Development of chemicals for stimulation that are compatible with formations and EOR chemicals and processes

8. Horizontal Drainage Wells

Many reservoirs are affected by gravity drainage as a primary means of recovery. Simulation of the effectiveness of horizontal wells to improve the gravity drainage process is an important consideration. It could also impact other processes previously described.

Example Projects

1. Simulation and assessment of EOR process performance with horizontal drainage-well patterns

9. Waterflooding

Waterflooding is an established secondary recovery process. A very large percentage of current production in the United States is from fields that are being waterflooded. There still exist areas of research that would lead to process improvement.

Example Projects

1. Examine significance of water quality on performance

Reservoir Evaluation and Monitoring for EOR

It is necessary to evaluate and screen reservoirs to determine their suitability for implementation of an EOR process. In general, processes must be designed specifically to meet reservoir conditions. More reliable methods for screening would be useful. Additionally, better methods to diagnose problems that existed in any prior recovery processes that were implemented, such as a prior waterflood, could lead to design of more effective EOR processes.

Once an EOR process is initiated it is important to monitor the behavior. Methods of measuring the movement of flood fronts, vertical sweep, etc., might be expected to lead to process improvements. The methods of evaluation and monitoring should be relatively low cost so that they could be widely implemented.

Activities

1. Process Monitoring

Research might lead to improved methods of monitoring process performance during the time period a process is being conducted. This would allow adjustments in design to improve performance. The information would be useful in design of subsequent applications of the same type or similar processes.

Example Projects

1. Simulation of production and observation well responses to EOR processes
2. Interpretation of cased-hole logs
3. Interpretation of transient pressure measurements
4. Development of improved tracer-interpretation methods
5. Laboratory and/or theoretical study of effects of EOR fluids on log response
6. Seismic monitoring of fluid flow

2. Screening/Diagnostics

Research could lead to methods of diagnosing problems in prior waterfloods such as poor volumetric sweep efficiency, channelling, etc. Improved methods of screening would allow the selection of candidate reservoirs with a greater degree of certainty.

Example Projects

1. Development of novel techniques to characterize fluid distribution in pores (saturations, nonflowing fractions, etc.)
2. EOR screening guidelines based on the chemistry and physics of the process--including implications of environmental and geographic considerations
3. Screening guidelines for profile modification based on the chemistry and flow behavior of the treatment process

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
A. Rock/Fluid Properties and Interactions									
1. Rock/fluid interactions	1								
a. Methods for characterizing and altering wettability b. Mineralogy and pore-structure effects on fluid distribution c. Advancement of CAT-scan and NMR imaging methods d. New approaches to the study of rock/fluid interactions e. Laboratory investigation of capillary pressures and relative permeabilities for enhanced-recovery processes f. Development of new or improved methods for predicting relative permeabilities for enhanced-recovery processes g. Fundamental investigation of thin-film drainage and flow recovery mechanism h. Predictive models of mineral-fluid reactions i. Characterization and permeability implications for fines movement in porous media									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $ < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
2. Fluid properties	1								
a. Predictive models for density, viscosity, and phase behavior of reservoir/EOR fluids									
b. Laboratory measurement of reservoir-fluid physical properties at high temperatures and pressures									
3. Rock properties	1								
a. Porosity-permeability correlations and their dependence on reservoir conditions									
b. Laboratory study of compaction, subsidence, rebound, and creep effects on physical properties such as porosity and permeability (especially for simulating fractured reservoirs and permafrost environments)									
B. Increased Volumetric Sweep Efficiency									
1. Mobility control	1								
a. Viscosifiers for CO_2 systems (polymers, foams, etc.)									
b. Development of CO_2-external foams									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH — AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
c. Development of new viscosifying agents for high-temperature and high-salinity applications									
d. Characterization of emulsion flow in porous media									
2. Near-well (profile control) and in-depth permeability modification	1								
a. Development of polymer-gel systems with controlled gelation time to allow flexibility in selective placement									
b. Development of methods involving chemical reaction and precipitation for plugging selected regions of a reservoir									
3. Operational strategies	2								
a. Simulation of gel placement and its effect on process performance									
b. Completion strategies									
c. Optimization of sweep efficiency through location of wells and/or use of horizontal drainage wells									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS → ACTIVITIES → EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
C. Prediction of Field Performance from Laboratory Studies									
1. Laboratory studies	1								
a. Dispersive mixing									
b. Viscous fingering									
2. Process simulation	2								
a. Grid-block size effects									
b. Numerical dispersion									
D. Improved Understanding of Process Mechanisms									
1. Miscible/immiscible gas	1								
a. Effect of mass transfer, e.g., dispersive mixing, on process performance									
b. Mechanisms of oil trapping/ bypassing in WAG miscible floods and role of mass transfer in recovery									
c. Effect on displacement behavior of three-phase region in CO_2-hydrocarbon displacement process									
d. Improved mechanistic description of viscous fingering									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
e. Role of combined viscous and gravity instabilities in process performance									
2. Foam/emulsion	1								
a. Definition of foam transport and oil-displacement mechanisms									
b. Effect of mass transfer, e.g., dispersive mixing, on process performance									
c. Correlation of fluid physical properties with process performance									
3. Steam	3								
a. Determination of factors controlling steam mobility									
b. Determination of factors controlling final oil saturation									
4. In-situ combustion	3								
a. Effect of dispersive mixing on process performance with gravity override									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
5. Microbial	3								
a. Fundamental study to elucidate mechanisms									
6. Micellar/polymer	2								
a. Determination of polymer/surfactant-interaction effects on process performance									
7. Polymer augmented waterflooding	2								
a. Determination of relative contribution of viscosity and permeability reduction to mobility reduction									
8. Alkaline	3								
9. Miscellaneous	3								
a. Definition of mobility-control and oil-displacement mechanisms for liquid-crystal system									

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
E. Process Enhancement									
1. Thermal	3								
a. Examination of thermal-recovery mechanisms and potential for light-oil targets									
b. Investigation of pressure effects in steam flooding shallow reservoirs									
c. New approaches for effective steam flooding in thin reservoirs									
d. Development of thermally stable chemicals (for foams, etc.)									
2. Chemical	3								
a. Development of high-temperature, high-salinity surfactants and polymers									
b. Investigations aimed at reducing sensitivity of phase behavior and interfacial properties to variations in temperature and salinity									
3. Miscible/immiscible gas	2								
a. Improvement in gas availability, e.g., membrane separation, etc.									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
4. Enhanced gas recovery (EGR)	3								
a. Recovery of gas from gas hydrate systems									
b. Development of methods to recover gas from unconventional sources, e.g., Devonian shales									
5. Single-well EOR	3								
a. Laboratory and simulation study to support development of quick-response methods like cyclic CO_2									
b. Processes for small reservoirs									
6. Novel EOR	3								
a. Development of solvent process for heavy-oil recovery									
7. Stimulation	3								
a. Development of chemicals for stimulation that are compatible with formations and EOR chemicals and processes									

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
8. Horizontal drainage wells	1								
a. Simulation and assessment of EOR process performance with horizontal drainage-well patterns									
9. Waterflooding	2								
a. Examine significance of water quality on performance									
F. Reservoir Evaluation and Monitoring for EOR									
1. Process monitoring	2								
a. Simulation of production and observation well responses to EOR processes									
b. Interpretation of cased-hole logs									
c. Interpretation of transient pressure measurements									
d. Development of improved tracer-interpretation methods									
e. Laboratory and/or theoretical study of effects of EOR fluids on log response									
f. Seismic monitoring of fluid flow									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
2. Screening/diagnostics	2								
a. Development of novel techniques to characterize fluid distribution in pores (saturations, non-flowing fractions, etc.)									
b. EOR screening guidelines based on the chemistry and physics of the process—including implications of environmental and geographic considerations									
c. Screening guidelines for profile modification based on the chemistry and flow behavior of the treatment process									

*1,2, or 3

STIMULATION AND COMPLETION

Geoscience Institute
Technical Subcommittee Report

for

U.S. Department of Energy
Office of Fossil Energy

Prepared by

Richard A. Startzman, Texas A&M University*
Ralph W. Veatch, Amoco Production Research Co.*
James Brill, University of Tulsa
Gerald R. Coulter, Sun Exploration and Production Co.
Ali Daneshy, Haliburton Services Company
James T. Engelder, Pennsylvania State University
Alfred D. Hill, University of Texas at Austin

*Subcommittee Co-chairmen

STIMULATION AND COMPLETION TECHNOLOGY

PROBLEM DEFINITION

Well stimulation and completion technology is essential for oil and gas to flow from a subsurface formation, into a wellbore, and to the surface. It is by far the most commonly used technology to increase and/or optimize either well producing rates or for well injectivity. In many reservoirs, it is the only technology available for increasing proved reserves.

Well stimulation and completion technology research can potentially increase U.S. daily oil and gas production on the order of 20 percent and reserves by approximately the same amount. At a price of $18/BO, for current rates of 10.5 MMBOE/D and 50 percent probability of successfully implementing research, this equates to an annual incremental increase of about $7 billion.

BACKGROUND AND STATUS

Well stimulation and completion covers a broad spectrum of varied technologies. It probes deeply into the wellbore and the reservoir extremities. It addresses movement of oil and gas through perforations and to the surface. It involves measuring, analyzing, and predicting the flow potential in each segment from the reservoir extremity to the surface. It relates to removing restrictions in the formation and the wellbore. It requires evaluating and quantifying the existence of commercial hydrocarbons in both open and cased holes. In addition to being essential to primary production, it is an essential ingredient to implementing enhanced oil and gas recovery processes Today, even after a dozen decades of drilling and production developments, there are still many methods, devices, processes, and practices that need significant improvements. There are technologies which do not exist today that would greatly enhance our abilities to increase both producing rate and proved reserves.

RESEARCH APPROACH

The broad spectrum of technologies necessitates a wide variety of research approaches. The research areas include:

Hydraulic Fracturing
Monitoring and Control System
Acidizing and Other Chemical Stimulation
Perforating
Reservoir and Wellbore Interacting
Production Logging
Horizontal Wellbores
Explosive Stimulation
Sand Control

Cementing
Workover and Remedial Processes
Formation Evaluation

Research requirements range from basic concepts to applicable practices, including theoretical developments, computer simulation, evaluation/prediction engineering, and application techniques.

One area that was intentionally omitted from the consideration stated here was that of tool design, construction, and materials research. This was thought to be outside the current scope of "Geoscience." This omission does not imply that work in these areas is not essential to the advancement of stimulation and completion technology, nor that some of the suggested areas are not dependent upon new and novel tools, equipment, and devices.

Screening and prioritizing among the host of projects deemed worthwhile for current research have identified four highly significant areas as the most urgent and the most promising. Each of the following expanded descriptions details these areas as offering the greatest incentives for accomplishment, the highest probability of success, and the most clearly identifiable research approaches and programs.

RESEARCH AREAS

Measurement of Fluid Saturations Behind Pipe

When consideration is given to the need for information of reservoir conditions in the vicinity of the wellbore over the life of a field, it is readily apparent that one of the most pressing areas for research is on methodology for log determinations and interpretation through well casing. Considerable advances have been made in tool and techniques for log response in cased holes, and results to date have been sufficiently encouraging to warrant continued research in this area.

Analyses of log responses are needed to determine both the qualitative and quantitative values of various reservoir parameters. Such properties as water/hydrocarbon saturation, amount and extent of formation damage, the nature and extent of formation stimulation and changes of permeability during the life of a well are of the utmost importance. Significant improvements are needed to increase the reliability and decrease costs of these methods if they are to become routine over the life of a reservoir. Theoretical studies and modeling of responses are required to provide insight into this promising area.

Hydraulic Fracturing

When looking at the major objective of "oil in the tanks," it appears without question that the most rewarding achievement of Production Engineering during the last quarter century has come from well stimulation by hydraulic fracturing. Probably no other production development has made more oil available than the reserves made recoverable in low permeability formations and low productivity reservoirs by the fracturing operation. Although this procedure has been most rewarding, its prediction, design, and control still leave a great deal to be desired.

Of paramount importance probably is a greater knowledge of the importance of the influence of rock mechanics and a better understanding of the actual role of in-situ stresses in subsurface rock formations. Further, greater insight into the interaction of the rock-fluid system in a propagating fracture and the deformation of the poro-elastic media in heterogeneous formations holds out considerable promise for superior simulation which is essential for prediction, design, modeling, and control of the fracturing process. These are all vital when coupled with field verification of the operation.

Horizontal Wellbores

The emerging practice and increasing interest in horizontal drilling together with the intriguing well behavior and promise of improved oil recovery, especially EOR, calls out for a whole new direction of reservoir engineering research in this new bottomhole configuration. All of the old problems confronted in vertical wells call for a refocused research endeavor into questions ranging from drilling to well completion, well testing to production operations, and all reservoir engineering areas from pressure-production relations and multiphase fluid flow to simulation and modeling for reservoir behavior prediction and management.

The potential for contacting a greater fraction of highly heterogeneous formations, to connecting greater segments of fractured, fissured, and jointed rocks, as well as the normally lenticular, stratified clastic reservoirs, is justification for a concerted research program in this promising reservoir development procedure.

Cement Bond Logging

Interpretation of cement bond logs in vertical holes has frequently posed problems in determining the effectiveness of the seal between cement and the pipe and the cement and hole wall. When coupled with nature and uncertainties associated with displacement techniques in both primary and squeeze cementing operations to achieve effective zone isolation, severe requirements are placed on interpretation of bond logs to provide the assurance needed. Considerable advances have been made in bond logging tools to provide improved quality and quantity of information at reasonable costs. However, interpretative techniques have not kept pace. Numerical analyses of the logs and modeling of the system are promising research avenues to provide the assurances needed.

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
A. Formation Damage									
Formation damage created during the initial drilling, workover operations or during the production or injection life of a well can drastically affect the efficiency of recovery. An improved knowledge of the mechanisms of damage, materials to prevent damage are needed.									
1. Core/cuttings methods to predict/analyze formation damage susceptibility	2	X							
2. Chemical additives to prevent damage	2	X							
3. Empirical/theoretical models to simulate and explain formation damage	2	X							
B. Horizontal Wellbores									
The application of horizontal wellbores for enhanced recovery of oil and gas can provide a quantum advancement in efficiency of recovery. There are a large number of stimulation and completion questions which remain to be answered prior to optimizing the application of horizontal wellbores. These relate to selecting the location and planned completion type, prediction of expected production, and the actual completion and stimulation of the horizontal hole.									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH (AREAS → ACTIVITIES → EXAMPLE PROJECT)	Priority*	EST. ANNUAL $ < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
1. Reservoir candidate screening This includes developing methods to select appropriate reservoirs for horizontal completions.	2	X							
2. Completions (radius, orientation, location in pay, type) This research would address mechanical problems relating to completion geometry in horizontal wellbores.	1	X							
a. Stimulation						X			
b. Wellbore cleanout						X			
c. Formation and production logging							X		
d. Hole stability						X			
e. Artificial lift							X		
f. Perforating						X			
g. Cementing						X			
h. Interval isolation						X			
i. Formation damage							X		
j. Sand control								X	
k. Workovers						X			
l. Corrosion, paraffin control, scaling						X			

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
3. Production modeling and simulation	1	X							
a. Simulation of fracture systems						X			
b. Coning						X			
c. Flood patterns						X			
C. Perforating									
Perforating cased holes is the standard industry technique to communicate the reservoir with the wellbore. Evidence exists which suggests that the shaped charges currently used in the industry are inefficient in communicating the reservoir with the wellbore. Methods to relate surface performance to actual downhole performance is necessary before significant improvements can be made. Of importance is the effect of stress, formation, and pipe on penetration and hole size. Development of new and novel techniques for penetration and designed hole size is essential to advance perforating technology.									
1. Downhole performance evaluation techniques	1	X							
Methods are needed to evaluate the actual performance of voidages created by shaped charges in pipe, cement, and formation under actual downhole conditions.									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH (AREAS / ACTIVITIES / EXAMPLE PROJECT)	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
2. Stress effect on charge performance This would involve studies of the effects of formation stress on the characteristics of perforations created by shaped charges.	1	X							
3. Novel technology	2	X							
a. Hostile environment applications						X			
D. Reservoir and Wellbore Interaction The interactions between the reservoir and wellbore are poorly understood. Current behavior simulation methods for each treat the other in an oversimplified manner. More rigorous coupling will permit better estimation of well productivity and improved understanding of transient well test analysis.									
1. Modeling multiphase flow and inflow performance behavior in completion intervals Rapid changes take place in the composition of fluids near the well and within completion intervals. Detailed studies of the multiphase behavior of reservoir fluids within and across	1	X							

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
completion intervals can be useful in improving the production efficiency of completions.									
a. Near-wellbore phase behavior effects						X			
2. Transient phenomena	1	X							
Phase inversion and other short-lived multiphase phenomena occur in the wellbore during well shut-in and start-up. Studies are needed to understand the way these phenomena affect transient well test interpretation.									
a. Effect of wellbore transients on interpretation of well test data						X			
E. Workover and Remedial Processes									
Wells undergo a series of changes during their lifetimes. Improved recovery methods may require numerous corrections in completion interval and injection profile control. Improved methods should be available to monitor these changes and facilitate corrections when necessary.									
1. Downhole applications	3	X							
2. Downhole diagnostic methods	3	X							

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
3. Profile control	2	X							
a. Injection wells						X			
b. Production wells							X		
F. Formation Evaluation									
Near-well formation evaluation is becoming increasingly important as advances in well testing and logging tools occur. The need here is to focus on determining those properties that affect the quality of well completions.									
1. Methods to measure hydrocarbon/water saturations behind pipe	1	X							
Considerable advances have been made in cased hole logging methods. However, there is still room for significant improvements to reduce costs and increase the accuracy of these important measurements taken during the life of a reservoir.									
2. Methods to determine amount/extent of formation damage	2	X							
3. Modeling of log responses	2	X							

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
4. Methods to allow continuous measurement of in-situ permeability	2	X							
a. Application of NMR technology						X			
5. Methods to measure composition and mechanical properties of rock	3	X							
G. Monitoring and Control Systems									
The ability to monitor downhole and sometimes even surface data is an essential ingredient for improving well and reservoir productivity. In particular, monitoring downhole data without a wireline can significantly increase our understanding of reservoir/wellbore behavior. A by-product of these measurements will be to develop means of controlling surface or downhole well conditions to enhance productivity. They also allow us to do things we can do right now, such as downhole quality control and job monitoring during fracturing.									
1. Remote control applications	3	X							
2. Downhole to surface data transmissions	1	X							
Improvements in this area should be directed toward increasing data quality and reliability, while decreasing costs.									
a. Wireless communications						X			

*1,2, or 3

RESEARCH: AREAS → ACTIVITIES → EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
H. Hydraulic Fracturing									
In most reservoirs in the United States hydraulic fracturing is an integral part of well completion. In many areas wells do not produce economically without fracturing. Hydraulic fracturing increases production rate, economic reserves, and access to remote areas of the reservoir.									
1. Rock mechanics and in-situ stress characterization	1	X							
Increased awareness and understanding of actual rock stresses as they exist in the earth will improve our ability to predict orientation and other physical fracture features.									
a. In-situ stress profiling						X			
2. Fracture conductivity	1	X							
Studies are needed to improve our understanding of the effects of connate and injected fluids on fractures and proppant systems.									
Long-term hostile environment effects						X			

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH (AREAS / ACTIVITIES / EXAMPLE PROJECT)	Priority*	EST. ANNUAL $ < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
3. Fracturing processes	1								
An important area of research is one that seeks an improved understanding of fracturing in various economically important types of reservoirs.									
a. Coal degasification						X			
b. Heavy oil/tar						X			
c. Lenticular sands						X			
d. High-permeability/poorly consolidated rock						X			
4. Fracturing fluid behavior	1	X							
An important subject of research concerns the physical properties, and changes in the properties, of fracturing fluids during the fracturing process.									
a. Proppant transport and rheology									
b. Fluid loss studies									
5. Diagnostics	2	X							
a. Fracture geometry mapping									
b. Propagation behavior									

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
6. Simulation and modeling Improved numerical modeling methods, coupled with actual field verification, is a significant area of research.	1	X							
a. Fully 3-D simulation							X		
I. Acidizing and Other Chemical Stimulation In carbonate reservoirs, acidizing is a very effective way of near wellbore damage removal and increasing well productivity. To perform an optimum acidizing treatment we need to be able to selectively allow contact between acid and rock, control some of the undesirable effects of acid, and understand and quantify acid/rock interactions. Chemical reactions are also used to remove scale or paraffin deposition in the wellbore, thus removing obstacles to production.									
1. Diverting to insure total zone treatment	2	X							
2. Formative fluid/wellbore interactions (corrosion, paraffin, scale)	2	X							
a. Fluid leak-off						X			

*1,2, or 3

RESEARCH AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $ < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
3. Downhole application processes	2	X							
a. Viscous fingering						X			
b. Etching patterns						X			
c. Temperature effects and reaction rates						X			
4. Acid/fracture interaction	2	X							
5. Numerical modeling of matrix acidizing Detailed models of the fundamental acid reaction process will lead to further understanding of acidizing and may encourage improvements in the methods.	1	X							
a. Reaction kinetics						X			
J. Explosive Stimulation Explosives were used to remove wellbore damage in the early days of petroleum production. The techniques and materials have drastically changed since then. Even at present times, use of explosives can increase well productivity/injectivity in certain reservoirs. The fractures created by explosives have a different pattern and distribution than those created hydraulically.									
1. Mechanisms and rock mechanics	3	X							

*1,2, or 3

RESEARCH (AREAS → ACTIVITIES → EXAMPLE PROJECT)	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
2. Applications	3	X							
a. Numerical simulation						X			
K. Sand Control									
Production of sand mixed (even in very small amounts) with reservoir fluids is a serious problem in some wells. Advanced identification of problem wells gives the production engineer a chance to take preventive measures. In addition, industry needs to more thoroughly understand why and when sand is produced, measure its amount, design and evaluate preventive measures, and monitor and control their performance.									
1. Problem identification from logs and other data	2	X							
a. Statistical studies of effect of log response on tendency to sand							X		
2. Downhole sand retention methods and placement techniques	3	X							
a. Application of expert system in sand retention						X			
3. Process simulation and monitoring	3	X							
4. Formation consolidation processes	2	X							

*1,2, or 3

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
5. Sand production measurement and monitoring	2	X							
6. Application to thermal recovery processes	2	X							
L. Cementing Cementing allows for zone isolation and control of injected fluids into the reservoir. A number of areas needs to be further investigated to improve on this important portion of well completions. Industry sees the need for improved methods to evaluate primary cementing jobs and to improve on primary and squeeze cementing techniques as necessary to advance the efficiency of enhanced recovery.									
1. Displacement mechanisms studies Additional detailed work needs to be done to improve our understanding of the way cement slurry fills the space between casing and the wellbore. This improved understanding may lead to improvements in the success rate of primary cementing.	1	X							
2. Bond logging interpretation methods Advances in bond logging tools have improved the quality and quantity of information available. Further research needs to be done to arrive at more reliable interpretation of existing data.	1	X							

*1,2, or 3

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $				TIMING			
		< $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	< 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
3. Determination of wellbore circulating temperature profile	2	X							
a. Determination of in-situ rock thermal properties						X			
b. Measurement of actual temperatures							X		
4. Simulation and modeling	2	X							
5. Novel primary and squeeze cementing techniques	2	X							

*1,2, or 3

RESOURCE ASSESSMENT, DATA BASES AND TECHNOLOGY TRANSFER

Geoscience Institute
Technical Subcommittee Report

for

U.S. Department of Energy
Office of Fossil Energy

Prepared by

James M. Forgotson, Jr., University of Oklahoma*
William F. Diggons, Schlumberger*
Samuel Ameri, West Virginia University
(K. Aminian, Alternate)
John S. Fischer, Landmark Graphics Corporation
John Grace, ARCO Exploration and Development
Charles G. Groat, Louisiana Geological Survey
Robert A. Mason, Mason Production Company
Edward H. Mayer, Thums
E. Donald McKay, Illinois State Geological Survey
(Subhash Bhagwat, Alternate)
David E. Powley, Amoco Production Company
Peter R. Rose, Kansas State University
Philip H. Stark, Petroleum Information

*Subcommittee Co-chairmen

August 29, 1988

RESOURCE ASSESSMENT, DATA BASES, AND TECHNOLOGY TRANSFER

PROBLEM DEFINITION

Successful implementation of a program for improved recovery research will depend on effective technology transfer from research groups to industry and the demonstration of economic benefits to decision makers who will fund such projects. Determination of the quantities of oil and gas remaining in discovered fields that are not classified as producible reserves and the amount that is mobile is necessary to establish national energy priorities and to plan research activities to improve the recovery of these resources. A comprehensive national resource assessment requires the development of an appropriate methodology using existing data bases to determine the geographical and geological distribution of various categories of unproduced hydrocarbons based on geologic, engineering, and physical factors, as well as the economic limits that influence recoverability. The assessment of resource size for each category will provide a logical basis to establish priorities for research and technology development. Reservoir framework, reservoir characterization, and determining fields suitable as candidates for improved recovery studies will also require the use of existing data bases. New information generated from research projects sponsored by the Geoscience Institute must be put into a data base suitable for use by other research and industry groups. It is important that technology transfer begin with the initial planning of projects and continue through completion of the program.

BACKGROUND AND STATUS

Resource Assessment

Previous public sector studies to determine the amount of unproduced oil and gas contained in known reservoirs have been conducted at a cursory level of detail. This is particularly true for the estimates of the mobile oil and gas resource. A critical research area requiring attention is the grouping of reservoirs that have internal similarities of geologic and engineering parameters that permit characterization of the additional resource and its accessibility by analogy. The development of a mobile oil data base and computer methodologies to facilitate the assessment of the additional potentially recoverable oil resources should be the top priority for the recovery research project. In 18 to 24 months this effort could preliminarily identify and quantify improved recovery opportunities for industry at a cost of less than $2 million. After the initial stage, further refinement of the data base is envisioned.

Data Bases

Data base development should be a key function of the Institute. Their consideration must be included in the development of an overall project plan and for policy determination. Data bases impact the overall cost and effectiveness of conducting the critical resource assessment and impose consistent methodology and reporting procedures to permit the transfer of research results. A board or committee is needed to establish and to define data base policies for the benefit of the overall initiative and to advise on data base standards, designs and implementation. Establishing new data base standards and new data element definitions that are unique to this type of study will be required. Policies must be established regarding the use of existing commercial data and potential commercialization of the new data developed during the project. Employment of a librarian or administrator to implement standards and use of data bases is envisioned.

Data base structures and their implementation are considered a research topic because of the importance and complexity of implementing computerized data management that is necessary to integrate various geoscience research programs. Data base implementation is paramount in the Institute's research programs, especially in the area of transferring research information to the field. The trend toward publication of fewer raw data in scientific journals indicates a significant need for alternative means of preservation and distribution of data. The Institute must insure that research activities include an aggressive program of data capture and archival storage. Data bases built by the Institute's research projects will provide the basis for expansion of research, revised and improved resource assessment, and rapid dissemination of all old and new data to those who do not now have access to the information.

Effective communication of research results in a form that is immediately applicable to the oil field is a major goal of the Institute. Computer data bases and computer techniques for technology transfer require evaluation. Operators need the results of research interpreted for their unique situations and evaluated in economic terms. "Technology Transfer" should include the development of innovative computer approaches to conduct probabilistic economic evaluations which are needed to assist operators in comparing and selecting suitable techniques and for evaluation of risk.

Existing computer hardware and software technologies have the capabilities to manage both the type and quantity of information generated by research activities. These systems (hardware plus software) are available in a variety of price ranges and sizes. The principal criterion for selection of a particular system by a research project should be its ability to process the data for the project. The system must be capable of importing and exporting data and software in a format compatible with other Institute-supported systems. The goal of the Institute is to present information to operators in a form suitable to their needs, which necessitates compatibility with inexpensive desktop systems available to small operators. Specialized software for simulation of physical processes will need to be modified or created for new research developments. Quality assurance for these programs could be a responsibility of the Geoscience Institute through its designated committee or panel.

Technology Transfer

Most field operators own an interest in and are responsible for valuable, depleting, income-producing properties. They tend to be reluctant to undertake any operation which may result in deferred production or damage to well equipment or producing reservoirs. They are not inclined to "try something new" that has any risk involved. Many independent operators do not have access to, technical appreciation of, or confidence in many current geotechnical procedures so their attitude generally is "let someone else go first. I will follow after I see that the procedure will not endanger either my wells or reservoir." Unless current technology, research results, and appropriate economic analyses are effectively transmitted, many oil fields will probably never be fully exploited; much mobile oil will be left in the ground, not for technical reasons, but for cultural or situational reasons.

Widespread research and employment of state-of-the-art measures for increasing the recovery of mobile oil is best carried out in an atmosphere of willing cooperation between technical advocates and field operators. One may reasonable anticipate that modern technology will not be employed if suspicion or coercion are sensed. Moreover, improved recovery projects will be profit-driven. Therefore, it is necessary early in the program to disseminate the important technology and demonstrate the economic viability of properly designed, improved recovery projects. Operators should be involved in the identification of fields that have a high probability for economically successful improved recovery programs.

Identification of the "target audience" in each local area is extremely important. For example, in the Illinois Basin, consultants and companies with approximately 10 employees including field personnel may be the most receptive group. In parts of the Anadarko Basin, larger independents may be the critical group; in West Texas and the Gulf Coast, it may be the major companies. Many small operators do not employ a geologist or engineer except in a consulting capacity. Others are very sophisticated in the technology and economics of field operations.

Most of the mobile oil that is not going to be recovered through existing wells is in large fields. Many of these fields are shallow and under favorable circumstances the economics could support the recovery of significant amounts of mobile oil by targeted infill drilling and improved waterflood operations. In many old fields, recovery could be improved through better formation evaluation, methods, and completion procedures. However, the multiple ownership in many fields makes more difficult the efficient application of appropriate recovery technologies.

Transfer of appropriate technology to a large and diverse group of operators requires special methods and resources that are not in place. Demonstrating favorable economics and overcoming the inherent risk aversion of many operators are major challenges to the widespread application of improved recovery technology. Research is required to develop effective methods of technology transfer to this clientele.

A successful technology transfer program must recognize that many operators are not technical people and do not have access to a highly trained technical support staff. Specific programs must be implemented to present the technical concepts and economics to this group. State geological surveys, state oil and gas associations, and local societies or professional organizations can play an important role, particularly in the planning and early implementation phases of such programs.

RESEARCH APPROACH

National Oil and Gas Resource Assessment Data Base

The use of existing data bases is the key to completing a timely and effective assessment of recoverable mobile oil and oil that can be recovered through enhanced recovery technology. The assessment should be based on a nationwide calculation of remaining mobile oil and gas using established production projection methods and existing commercial production data bases. The assessment should also use appropriate screening methods to determine the additional resource recoverable through various EOR methods. Commercial production data bases contain records for about 750,000 producing entities (wells, leases, units, etc.) that cover about 95% of current U.S. production. Computations and use of analogs would accommodate shut-in or curtailed production and water-drive reservoirs. The use of data on abandoned and mature reservoirs would help to identify patterns of production by reservoir type that would serve as models for detailed characterization studies.

A committee should be established to develop methodologies for use by the resource assessment team. Reservoirs categorized by factors such as existing EOR program, underpressured, type of oil, well spacing, water production, type of trap, drive mechanism, lithology, and depositional environment would be the basis for resource assessment. Methods would be developed to estimate by extrapolation the additional recoverable oil in each reservoir category.

The reservoir file would incorporate the Petroleum Data system which was funded by the USGS. The reserve calculations would provide a new framework for a reservoir summary data base that will report recovery research results.

Research-Support Data Bases

Appropriate data for a research effort would be assembled from existing components. The use of these data will be to screen and select reservoirs for additional study. Later it may provide the background for research projects, including reservoir characterization, reservoir framework analysis, EOR techniques, and reservoir performance predictions.

Each research project should compile all relevant data including computerized data and all relevant existing but not previously automated information. Much of this information resides in the files of state surveys, commercial data vendors, operators, core labs, and service companies and in old theses at universities. It might also be productive to tap the memories of retired engineers and geologists. Because many data may not be included in existing automated data bases, research groups should be encouraged to approach operators and others to obtain such data.

The number and types of data sets useful for analysis are immense. Some examples are the following: Stratigraphy, structure, seismic, logs, cores, samples, bibliographies, production/injection information, maps, cross sections, reservoir data, produced and injected fluid, salinities, crude compositions and properties, water compositions, and rock properties.

Research-Results Data Base

As research activities generate new information from models and analyses, these data must be assembled into a usable data base. Collection of data in a digital format would be encouraged where practical. Raw data collected by all research activities should be preserved. These data should include not only the primary measurements, but also the syntheses and conclusions drawn from the basic data. These include models of reservoir heterogeneity, assessment of the effectiveness of improved recovery techniques, play framework, sequence stratigraphy, and reservoir performance predictions.

Data Base for Technology Transfer

Effective communication of research results in a manner that is immediately available and applicable to the oil field operator is a major goal of the Institute. The role of computer data bases and computer techniques for technology transfer needs to be evaluated. Operators need the results of research interpreted for their unique situations and evaluated in economic terms. Innovative approaches to technology transfer may be necessary to assist operators in selecting suitable techniques and evaluating their risk.

A data base to support technology transfer will need to be available and usable by a broad spectrum of individuals ranging from technically sophisticated to unsophisticated. It should allow the operator to obtain answers about development strategies without necessarily providing all of the technical details.

Computerized technology transfer could provide custom simulations for users who need assistance in risk and economic assessments.

Technology Transfer

Current science and technology that can be immediately applied should be made available to research groups and interested operators through a presentation including both written and visual materials. Local groups or designated Institute representatives should inform operators by various media presentations of currently available science and technology applicable to recovering additional mobile oil from known reservoirs.

The technology transfer function should provide research groups and interested operators with the data necessary to make an enlightened selection of fields for study. Those fields that provide adequate data need to be screened for final selection for inclusion in detailed analysis and simulation studies.

Research results should be transmitted in summary form through presentations at professional and scientific society meetings and publication in existing scientific and professional journals. The Geoscience Institute should consider policy regarding workshops, seminars, short courses, and special publications. The Institute should prepare alternate plans for data dissemination, including who would control such activities: DOE, state surveys, or professional organizations. The Institute should work with state surveys and professional groups to organize and implement a proper forum to establish initial communication with operators at local or regional levels.

Successful implementation of the program requires dissemination of technology and demonstration of the economic potential of properly designed improved recovery projects early in the program. Operators should be involved in the identification of fields that have a high probability for economically successful improved recovery programs. To assist this effort, reservoir simulation programs should be developed for personal computers.

A goal of the Institute is to assist industry and its operators in the assessment and reduction of the risk related to recovery of additional oil. Procedures for assessing risk and profitability of proposed improved petroleum recovery projects need to be made available to independent field operators. There is also a need to investigate the economic factors that control the profitability of the small operation. Its importance rests on the realization that the widespread adoption of improved recovery technology by industry will be profit driven.

Demonstrating favorable economics and overcoming the inherent risk aversion of many operators is a major challenge to the widespread application of improved recovery technology. Research is required to develop effective methods of technology transfer to this unconventional clientele. State geological surveys, state oil and gas associations and local societies or professional organizations can play an important role, particularly in the planning and early implementation phases of technology transfer.

RESEARCH AREAS

Resource Assessment

Develop an improved methodology using existing data bases to estimate the quantities of unproduced mobile oil and gas that are not classified as proven reserves in discovered fields and the size of the resource recoverable by various EOR technologies. Categorize these resources by geological, engineering, and physical factors that influence recoverability. Estimate the additional quantities of oil and gas that can be produced from each category.

1. Geological/Engineering Assessment of Remaining Recoverable Oil and Gas in Discovered Fields

    a. Assemble committee of geoscience professionals from industry to provide input on the influence of geologic and engineering factors on hydrocarbon recoverability.

    b. Analyze the implications of past economic, regulatory, and historical practices on the field data which are being used to determine the quantity of accessible oil and gas potential (e.g., the effect of allowables, waterflooding, etc.).

c. Apply statistical techniques to available data bases for the purposes of determining relationships between geologic and engineering factors and the quantity of unproduced mobile oil and gas. Use appropriate screening methods to estimate the recoverable resource by various EOR procedures.

d. Conduct more detailed research to refine the initial assessment due to technological advances and consideration of additional geological and engineering data.

2. Economic/Regulatory Evaluation of Remaining Recoverable Oil and Gas in Discovered Fields

a. Determine what fraction of this resource is associated with stripper and low productivity wells. What are the implications for national resource potential? What are the opportunities available to independent operators? What regulatory structure would be most useful?

b. Estimate the amount and type of investment required from an engineering and geologic standpoint, to produce different fractions of the total technically recoverable mobile oil and residual oil resources at different price levels. This analysis would be conducted at the same level of aggregation as the technical analysis (i.e., at the level where internal similarity of geologic and engineering factors allows credible characterization of the resource and its accessibility).

Application of Existing Data Bases

The use of existing data base will substantially impact the cost and efficiency of conducting research in several of the Technical Program elements. The identification of available data bases and definition of procedures for their use applies to many research areas. Key activities regarding the use of existing data bases are:

1. Develop an inventory of and index to available digital, hard copy, and raw data resources that might apply to the Technical Program. Data from public, commercial, and proprietary resources should be identified and, where possible, made available to all researchers and industry. The possible commercialization of these composite data through on-line networks or other forms of distribution should be considered.

2. Develop a reserve data base and computer methodologies to facilitate the assessment of additional recoverable oil resources.

3. Develop methodology for use of the existing data bases in the reservoir framework and characterization studies. Coordination with study teams to establish research objectives, to determine what data and analyses are planned, and to develop specifications for access and use of existing data for the project will be required.

4. Develop methodologies to screen and identify types of reservoirs and specific fields suitable for targeted infill drilling and improved recovery. Characterize performance of type reservoirs under different enhanced recovery strategies.

5. Develop case histories and models that demonstrate the results and benefits of improved recovery techniques. These case histories should include economic analyses to show the economic potential of projects under a variety of price scenarios.

Development of New Data Bases

The major role of new data bases will be to facilitate research and analysis, and to document and transfer results of the funded research to the oil industry.

1. Data standards and policies for uniform data structures must be established early in the project. Standards would cover use of existing codes such as API well numbers, DOE- and state-assigned field and reservoir codes, etc. New data elements that are captured from each research activity must be defined and expressed by standard data element definitions, tables, and dictionaries. The use of data standards will assure that data and results from various research organizations can be composited and exchanged. The development of uniform data structures will be considered and evaluated for use in a variety of acceptable software systems.

2. Develop an inventory and index of research and program results to aid in technology transfer. (This would be an ongoing task throughout the project.)

3. Design summary data bases to transfer research results to industry. Such data bases might include tables that demonstrate conclusions, the reservoir summary data base, and case studies for specific categories of reservoirs with high potential for additional recovery.

Technology Transfer

1. Develop a Computer Data Base for Improved Hydrocarbon Recovery.

   a. Include data on sedimentary and stress environment of reservoirs, reservoir parameters, production, injection, remaining mobile oil, and economics where available.

   b. Expand initial data base as more information is obtained from existing sources and new Geoscience Institute research.

2. Communicate and Inform Operators, Professionals, Researchers, and Service Companies.

   a. Develop a standardized written and visual (35 mm slide) presentation regarding:

      1) the Institute, its work (GPI).
      2) the existing data sources and data bases (1 above).

b. Present information at industry and technical society meetings (adjusting the presentation to the group being addressed and for expertise of the speaker). Organizations contacted on national, regional, and local bases should include but are not limited to:

1) Independent Petroleum Association of America (IPAA)
2) Interstate Oil Compact Commission (IOCC)
3) Society of Petroleum Engineers (SPE)
4) American Association of Petroleum Geologists (AAPG)
5) Society of Professional Well Log Analysts (SPWLA)
6) American Petroleum Institute (API)
7) Society of Exploration Geophysicists (SEG)
8) Universities
9) Research organizations
10) Governmental agencies
11) Civic groups

c. Hold progress report forums on Institute research in conjunction with appropriate industry and technical society meetings. Holding forums in conjunction with existing meetings will avoid duplication, minimize travel costs, and lower chargeable personnel expenses. Progress report forums would not preclude presentation of significant results as a professional scientific paper at established technical society meetings and in professional journals. Such presentations and publications would be encouraged.

d. Establish a newsletter which would contain in brief abstract form results of Institute-sponsored work and related investigations by others. The newsletter should be less formal than the usual technical or professional society journals, offer very short delay in publication following submittal of an article, allow more pages of data than the journals, and have less restrictive standards for drafting and format. A newsletter would provide the basis for updating the improved oil recovery data base. The newsletter would be circulated to operators, professionals, service companies, and other researchers on a regular basis.

e. Study the possibility of establishing a periodical which would communicate new data in more detail to interested professionals, operators, service companies, and researchers.

f. Establish a technical report system communicating all pertinent data on significant findings. In addition to technical data, reports should include an appraisal of economics, including case studies, risk analyses, and cost sensitivity.

g. Transfer new data to both industry and students through various avenues of formal education.

1) Conduct short courses for industry (course level and content would be tailored to student needs and level).
2) Conduct university seminars for professors and students.

3) Introduce into existing university courses the need for an interdisciplinary approach to achieve improved oil recovery.
4) Encourage cross-disciplinary research programs in improved oil recovery for training of advanced degree professionals in the new broadened interdisciplinary approach to improved oil recovery.
5) Encourage introduction into the curriculum of new interdisciplinary graduate and upper division university courses in improved oil recovery.

h. Videotape comprehensive interviews with independents and consultants that do not prepare written papers. Use these tapes at forums and short courses and sell the tapes to appropriate groups for training purposes.

3. Develop New Techniques for Improved Oil Recovery Technology Transfer

a. Fund a pilot program that would permit an operator to understand the data and information requirements necessary for the start of an improved oil recovery project and the expected range of economic return from such projects. However, this service would not replace the need for field studies, laboratory tests, professional design, and competent implementation of a project. Rather, it would indicate the steps that should be taken in the screening, design, and implementation phases. If successful, such a program could be expanded to a regional basis. Also, a menu-driven computer program might be designed which would provide guidance on a dial-up basis. (Depending on cost and budget considerations, a fee might be required for this service.)

b. Develop interactive audio and video software based on "expert systems" and/or artificial intelligence concepts to inform professionals, operators, service companies, and researchers of the Geoscience Institute's work. Such software would provide background on existing technology and update the status of the Institute's and other research in improved oil recovery. More than one level of presentation of each type might be produced to satisfy the needs of different groups.

c. Develop a dial-up, menu-driven computer data base manager that would permit easy access of the improved oil recovery data base by technology type, region, formation, field or ongoing research. This data base manager would permit researchers, professionals, service companies, and independent operators to gain access to the data and permit them to obtain hard copy printouts of pertinent available technology and data.

d. Develop low-cost, menu-driven reservoir engineering software for microcomputers. The software can include fluid properties correlations, petrophysical analyses, traditional reservoir engineering techniques, the DOE enhanced recovery process models, and limited black-oil simulation capability. The software should be made available to professionals and operators in programs (a-c) above.

SUMMARY

Successful implementation of a program for improved recovery research will depend on effective technology transfer from research groups to industry and the demonstration of economic benefits to decision makers who will fund such projects. Determination of the quantities of mobile oil and gas remaining in discovered fields and the resource recoverable by various EOR techniques is necessary to establish national energy priorities, and to plan research activities to improve the recovery of these resources.

Previous public sector studies to determine the amount of unproduced mobile oil and gas contained in known reservoirs have been conducted at a cursory level of detail. A critical research area requiring attention is the grouping of reservoirs that have internal similarities of geologic and engineering parameters that permit characterization of the additional resource and its accessibility by analogy. The use of existing data bases is the key to completing a timely and effective assessment of recoverable mobile oil and the EOR resource base. The assessment should be based on a nationwide calculation of remaining mobile oil and gas using established production projection methods and existing commercial production data bases. The development of a mobile oil data base and computer methodologies to facilitate the assessment of the additional potentially recoverable oil resources should be the top priority for the recovery research project.

Data base development should be a key function of the Institute. Data bases impact the overall cost and effectiveness of conducting the critical resource assessment and impose consistent methodology and reporting procedures to permit the transfer of research results. The Institute must insure that research activities include an aggressive program of data capture and archival storage. Appropriate data for a research effort would be assembled from existing components. The use of these data will be to screen and select reservoirs for additional study. Later it may provide the background for research projects, including reservoir characterization, reservoir framework analysis, EOR techniques, and reservoir performance predictions.

As research activities generate new information from models and analyses, these data must be assembled into a usable data base. Raw data collected by all research activities should be preserved. These data should include not only the primary measurements, but also the syntheses and conclusions drawn from the basic data. The major role of new data bases will be to facilitate research and analysis and to document and transfer results of the funded research to the oil industry. Data standards and policies for uniform data structures must be established early in the project.

Existing computer hardware and software technologies have the capabilities to manage both the type and quantity of information generated by the envisioned research activities. The principal criterion for selection of a particular system by a research project should be its ability to process the data for the project and to import and export data and software in a format compatible with other Institute-supported systems. A goal of the Institute is to present information to operators in a format, which necessitates compatibility with inexpensive desktop systems available to small operators.

Most field operators own an interest in and are responsible for valuable, depleting, income-producing properties. They tend to be reluctant to undertake any operation which may result in deferred production or damage to well equipment or producing reservoirs, and they are not inclined to "try something new" that has economic risk involved. Unless current technology, research results, and appropriate economic analyses are effectively transmitted, many oil fields will probably never been fully exploited. Therefore, it is necessary early in the program to disseminate the important technology and demonstrate the economic viability of properly designed, improved recovery projects.

Most of the mobile oil that is not going to be recovered through existing wells is in large fields. Many of these fields are shallow and under favorable circumstances the economics could support the recovery of significant amounts of mobile oil by geologically targeted infill drilling and improved recovery operations.

A successful technology transfer program must recognize that many operators are not technical people. Specific programs must be implemented to present the technical concepts and economics to this group. State geological surveys, state oil and gas associations, and local societies or professional organizations can play an important role, particularly in the planning and early implementation phases of such programs.

A data base to support technology transfer will need to be available and usable by a broad spectrum of individuals ranging from technically sophisticated to unsophisticated. It should allow the operator to obtain answers about development strategies without necessarily providing all of the technical results.

Current science and technology that can be immediately applied should be made available to research groups and interested operators through a presentation including both written and visual materials. Research results should be transmitted in summary form through presentations at professional and scientific society meetings and publication in existing scientific and professional journals. A support function should be established either through the states or DOE, focused on both technology and economic assessment of anticipated projects.

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	$1MM - $5MM	$5MM - $10MM	> $10 MM	TIMING: < 2 Yrs	2 - 5 Yrs	5 - 10 Yrs	> 10 Yrs
A. Resource Assessment									
1. Geological and engineering assessment of remaining recoverable oil and gas in discovered fields	1	X							
a. Obtain industry opinion on the expected influence of geologic economic and engineering factors on recoverability						X			
b. Analyze the implications of historical practices on the data used to determine accessible oil and gas potential						X			
c. Determine statistical relationships between geologic and engineering factors and unproduced oil and gas potential						X			
d. Refine initial assessment in light of technological advances							X		
2. Economic/regulatory evaluation of recovery potential	2	x							
a. Determine the implication for national potential and opportunities for independent operators and regulatory structure							X		
b. Determine the investment required to produce different fractions of the recoverable resource							X		

*1,2, or 3

Resource Assessment, Data Bases, and Technology Transfer

(Summary of Research Areas and Activities)

RESEARCH: AREAS / ACTIVITIES / EXAMPLE PROJECT	Priority*	EST. ANNUAL $: < $1 MM	EST. ANNUAL $: $1MM - $5MM	EST. ANNUAL $: $5MM - $10MM	EST. ANNUAL $: > $10 MM	TIMING: < 2 Yrs	TIMING: 2 - 5 Yrs	TIMING: 5 - 10 Yrs	TIMING: > 10 Yrs
B. Existing Data Bases									
1. Develop an inventory and index to digital and hard copy data resources	1	X				X			
2. Develop a methodology for the assessment of additional recoverable oil resources	1	X				X			
3. Develop methodology to use existing data bases in reservoir framework and characterization studies	3	X				X			
4. Develop methodologies to screen and identify plays for targeted infill drilling and secondary recovery	2	X				X			
5. Develop case histories and economic models that demonstrate the results and benefits of improved recovery techniques	2	X					X		
C. Development of New Data Bases									
1. Establish data standards and policies for uniform data structures	1	X				X			X
2. Develop an inventory and index of research and program results to aid in technology transfer	2	X					X		X
3. Design summary data bases to transfer research results to industry	2	X					X		X

*1 2 or 3